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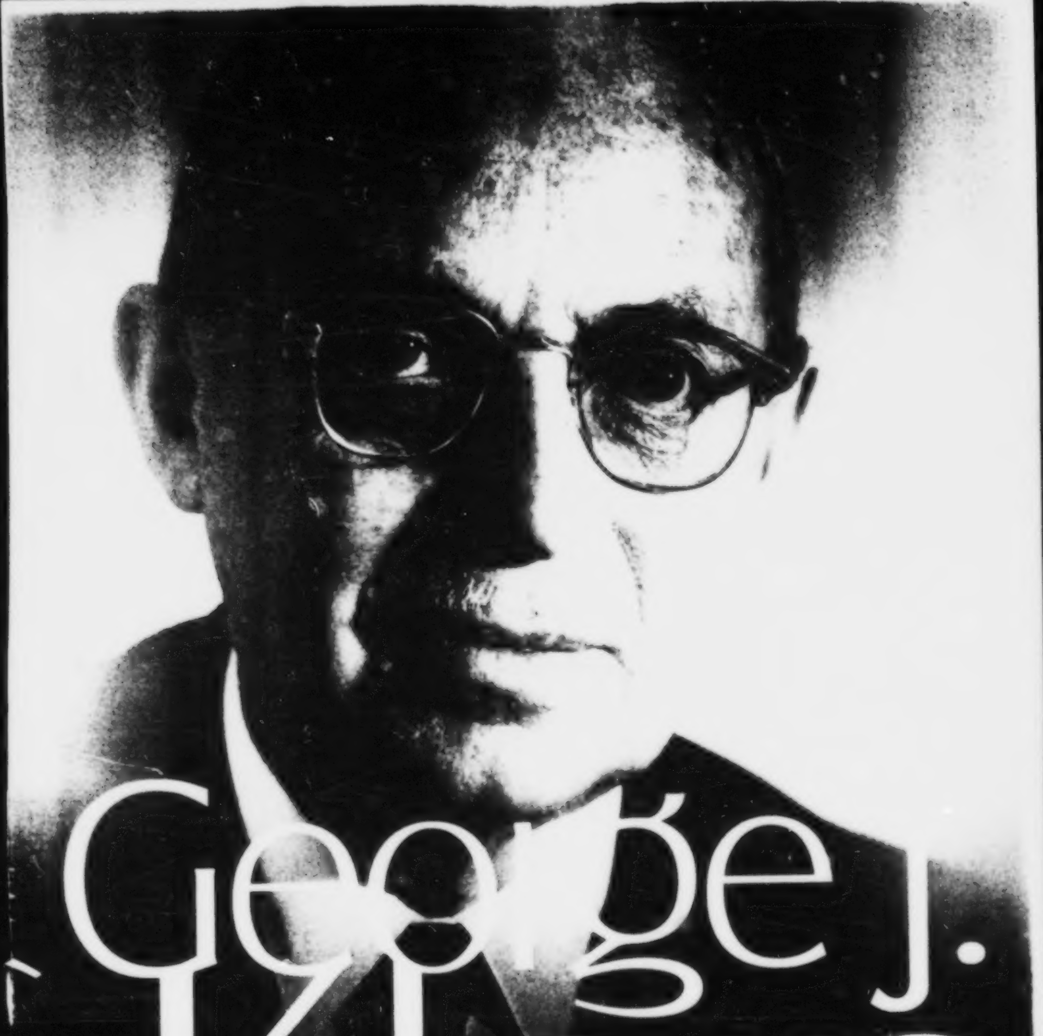

George J. Klein

The Great Inventor

RICHARD I. BOURGEOIS-DOYLE

George J. Klein

The Great Inventor

George J. Klein (1904–1992), a design engineer who spent 40 years at the National Research Council of Canada (NRC) laboratories in Ottawa, has been called "a Northern Edison" and is quite likely "the most productive inventor in Canada in the 20th Century". Spurred by the needs of great scientists and supported by talented technicians, he produced hundreds, possibly thousands, of ingenious devices, techniques, and tools; many of which influenced the growth and development of his country.

He helped to revolutionize aeronautical research in Canada by designing and building NRC's first wind tunnels in the 1930s, and he played a critical role in many of Canada's major scientific and technical contributions during the Second World War. The motorized electric wheelchair that he and his team built for quadriplegic veterans after the War was the first of its kind and contained features such as a joy stick and drive system that are still seen in electric wheelchairs today. Later, he collaborated on the first microsurgical staple gun used successfully to suture blood vessels. Klein was the chief engineer and mechanical designer for ZEEP, the first Canadian nuclear reactor and the first to go into operation outside the U.S. He was an internationally recognized expert in the mechanics of ice and snow, and his research in this field led to the international system for classifying ground cover snow and made it practical to put skis on bush planes, indirectly opening up vast areas of Canada to exploration and air transport services. Klein's expertise was also crucial to the success of the first military snow vehicle, the "*Weasel*", a project that was among his many top secret war-time projects and was intertwined with the creation of the First Special Service Force, "*The Devil's Brigade*".

In the early 1960s, Klein's retractable STEM antenna gave Canada a special place in the space age and was used in *Mercury*, *Gemini*, and *Apollo* spacecraft and in over one hundred other innovations. After retirement and well past the age of 70, Klein worked as chief consultant on gear design for the first Canadarm and then after his 80th birthday, he contributed to the system's further development within the Space Shuttle program.

A generous and kind man who would tear up at the sound of the national anthem, George Klein was deeply dedicated to his country and to helping others. His story "makes you proud to be a Canadian".

Michele Bourgeois-Doyle

Richard (Dick) Bourgeois-Doyle, Director of Government Relations at the National Research Council of Canada (NRC), has headed a number of special projects since joining the NRC Executive Offices in 1987. He previously served as Chief of Staff to the Minister of Science and Technology and the Minister of Fisheries and Oceans and was founder and start-up manager of successful technology and public relations firms. A former broadcaster and journalist, Bourgeois-Doyle has contributed to many books, articles, TV features, and radio programs on science history. He is a co-chair of the Thomas D'Arcy McGee Roundtable for Canadian Speechwriting.

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A Northern Edison and Inventions that Changed a Country

"Few books have traced and documented a life story of invention as comprehensively as Dick Bourgeois-Doyle's biography of George J. Klein, the foremost Canadian inventor of the 20th century.

This is an engaging and eminently readable book about a multifaceted genius who designed and created everything from radio antennas and nuclear reactors to the first practical electric powered wheelchair for quadriplegics.

It is an inspiring story for young and old from the budding inventor to the historians of science."

— Arthur J. Carty

National Science Advisor to the Prime Minister of Canada

"This story makes you proud to be Canadian."

— Roy Mayer

[illegible] and author of Inventing Canada

"A good — and readable — description of the work of a great inventor that is not only rich in information and technical facts, but also conveys a sense of occasion. It brings out — in an easy manner — George's generosity in helping others find solutions to their research problems. The chapters on skis in the air and on snow contain excellent examples of his ability to make highly significant national and international contributions to subjects peripheral to his principal areas of research."

— **Lorne Gold**

NRC Researcher Emeritus,
author of The Canadian Habbakuk Project,
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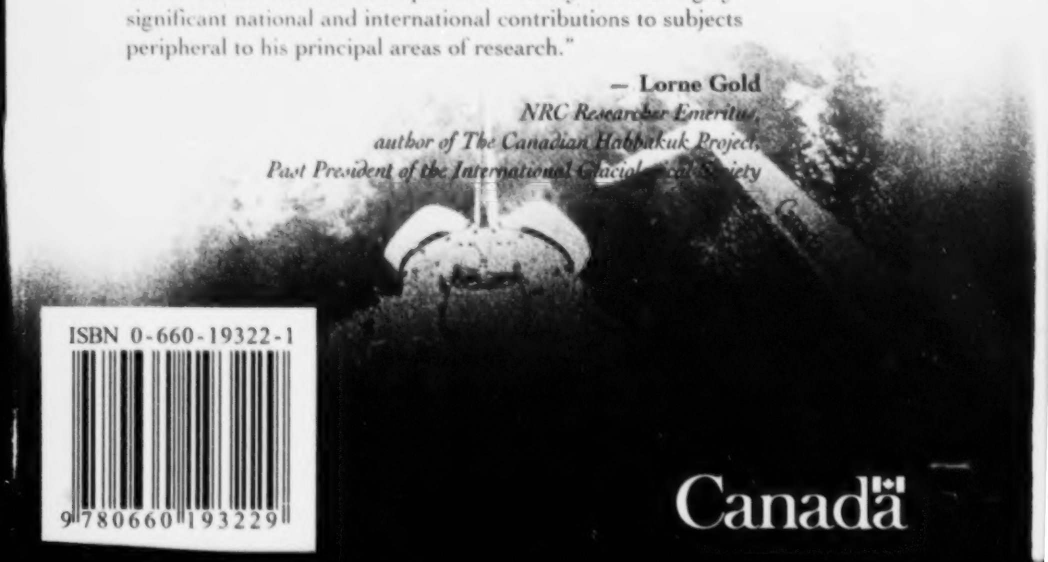

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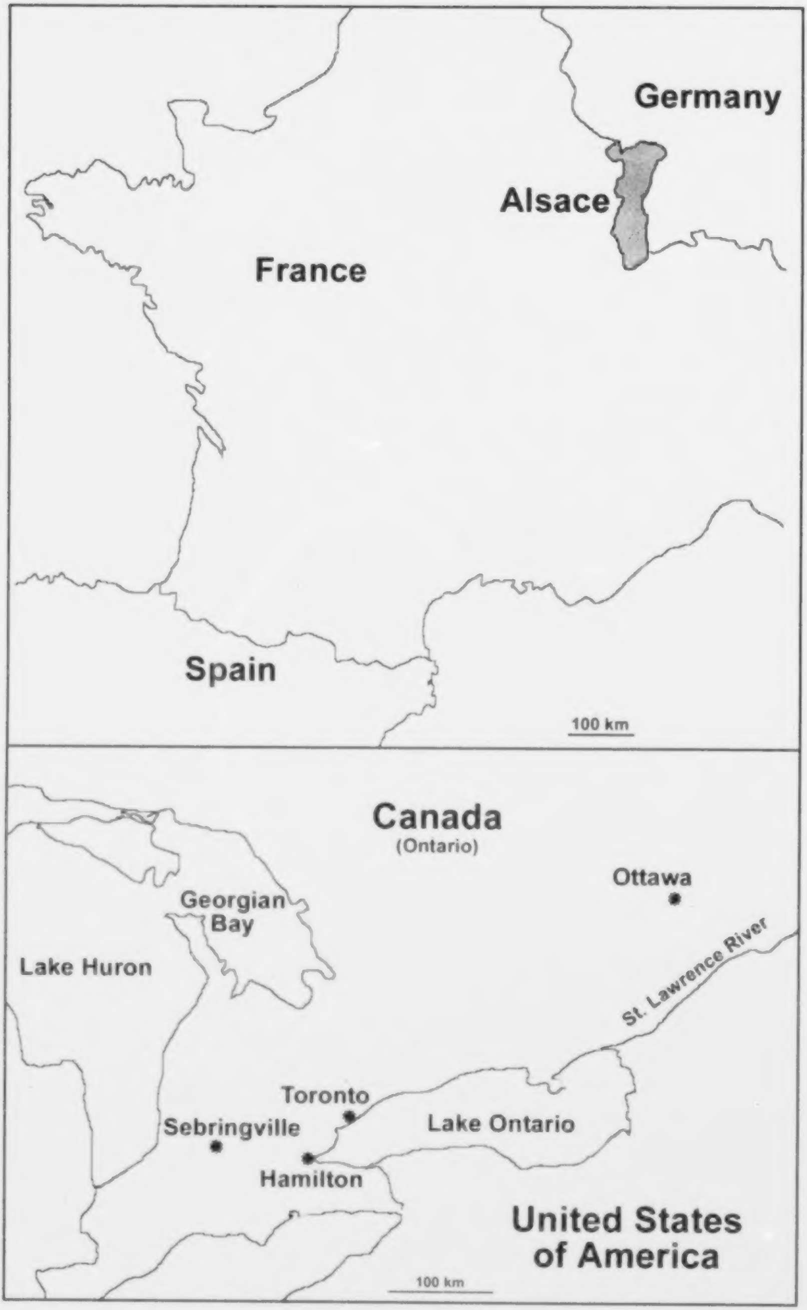
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THE GREAT INVENTOR

RICHARD I. BOURGEOIS-DOYLE
NATIONAL RESEARCH COUNCIL OF CANADA
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For Becky and Jonathon

May they see all of life's problems as opportunities for creativity

CONTENTS

Prologue ix
Chapter 1.
The Georgian Era 1
Chapter 2.
Helping Build Canadian Science 29
Chapter 3.
The Science of Skis in the Sky 69
Chapter 4.
The Devil's Machine 95
Chapter 5.
Canada's First Nuclear Reactor 115
Chapter 6.
The Seeds of Snow 139
Chapter 7.
The First Wheelchairs for Quadriplegics 161
Chapter 8.
A Thousand Odds and Ends, and a Few Bad Ideas 185
Chapter 9.
Fingerprints on the Arm 211
Chapter 10.
Brainstorming, Bicycles, and Bird Houses 229
Appendix 1.
Edison and Klein 241
Appendix 2.
Some Inventions, Designs,
and Innovations of George J. Klein 249
Appendix 3.
Timeline 252
Acknowledgements 261
Notes and References 263
Subject Index 284
Name Index 287

PROLOGUE

George J. Klein was one of the world's most prolific design engineers and inventors. Yet his surprisingly inspirational and instructive story may never have come to light had it not been for the unintended consequence of works by two men. One was Klein's supervisor, mentor, and friend for almost half a century: John Hamilton Parkin.

Parkin, the Director of the National Research Council of Canada's (NRC) Division of Mechanical Engineering for its first decades of existence, was a stern man with few close friends. He was known and addressed only as "Sir" or "Mr. Parkin" at work. He could have been regarded as condescending, cold, and arrogant by many of those who crossed his professional path. My first knowledge of Parkin induced similar thoughts, but through this project, I came to like him with a special affinity and respect. One reason I grew to like him was his obvious affection for Klein and admiration for his friend's talent, enthusiasm, and creativity.

Before arriving at NRC in 1929, Parkin had sown the seeds of national engineering research as a young professor at the University of Toronto where he taught and inspired many students. One was George J. Klein. In many ways, Klein was a younger, more hyperactive version of Parkin, and it is not a surprise to learn that the older man saw something special in this particular student. Parkin, like Klein, grew up interested in model making, technical subjects in school, and the exciting developments around human flight. However, being some thirteen years older, Parkin was also positioned to lay the groundwork upon which Klein and others could later conduct research and invent new devices. He recruited Klein to be the first true researcher at NRC in 1929, and he directed technical problems Klein's way for the next three decades. In this way, Parkin was a multi-pronged influence upon Klein's work.

With respect to this book, it is also important that Parkin continued giving lectures on Canadian aeronautical and mechanical engineering history right up until his death at 90 years of age in 1981 and that he made time, during his retirement, to record his reflections on the early years in his memoirs. In the late 1980s, I had occasion to seek out one of the few printed copies of the two-volume "Memoirs of J.H. Parkin" while writing a chapter on Klein for another book.[1] That someone might entitle his memoirs

"Aeronautical Research in Canada 1917–1957" struck me at the time as an expression of a significant ego and a limited perspective.

I was wrong on both counts. The memoirs, in fact, are the product of someone who not only knew the entire scope and depth of aeronautical research in Canada during this period, but in the entire world. Parkin was well travelled and well connected. He knew all of the great personalities and understood thoroughly the technologies and the engineering issues affecting almost every aspect of aeronautical design and research.

His memoirs are rich technical and historical resources that could probably add colour and content to dozens of books. They are also, perhaps unintentionally, expressions of modesty. While there is no doubt about whose perspective and experience the memoirs echo, the books are not the simple story of one man. They are testimonies to the works of many others. Parkin's memoirs describe a constellation of discoveries, inventions, experiences, events, and personalities with unique and impressive qualities. Yet one name is cited by the Parkin history of Aeronautical Research much more than any other when it came to technical innovation and inventions: George J. Klein.

My view of Parkin as a grand ego was further mollified when I learned that his first priority for retirement was not his own memoirs, but rather the chronicling of the life's work of Frederick Walker "Casey" Baldwin. Baldwin is still not recognized well-enough as the first Canadian to fly an airplane even though his name is customarily uttered in any mention of Alexander Graham Bell's team of aviation pioneers. Parkin felt that Baldwin's achievements had been overshadowed since his first flights took place in the United States, not in Canada where the national celebration of first flight is around that of J.A.D. McCurdy and the *Silver Dart* in Baddeck, Nova Scotia. Not to diminish McCurdy and others, but rather to promote Baldwin, Parkin wrote the book *Bell and Baldwin* (1964) linking the famous man with one that he felt deserved more recognition.[2] The most striking point about the work for me was the fact that Parkin, the gruff and seemingly cold engineer, was motivated to write the book mostly by his belief that his subject was a genuinely nice person and deserved better treatment in Canadian history.

It is a motive that pushed the writing of this book forward as well and is another element of the affinity I felt for Parkin and his work. In light of his extraordinary experiences described in the memoirs and of his original research on aviation history for *Bell and Baldwin*, Parkin's judgment of Klein as an exceptionally productive inventor is convincing.

Klein was certainly productive, always inventing new devices, designing prototypes, making models of his innovations, and solving engineering problems. He was too busy to document more than a faint skeletal description of his work. Often he would produce and deliver a unique, novel, and useful device or technique to a colleague in another laboratory to use in the context of a single experiment. These other projects would, in turn, be duly reported, but only in terms of what was discovered, measured or observed without regard for the special new tool used in the process let alone its designer.

At other times, secret records were purposely destroyed, and in still other cases, no records ever existed other than memories of the casual exchange of idea-laden words. Talking about ideas was a feature of Klein's place of work. It is, therefore, thanks only to personal accounts such as those set down on paper by Parkin that the full scope of Klein's involvement has filtered into a few of the formal chronicles of Canadian invention.

While Klein has been often overlooked, NRC on the whole has received fair treatment in many books and articles on Canadian science and technology history, and it has been examined by a number of journalists and historians.

One worthy of special mention here is the other person to whom I am indebted in this work: Donald J.C. Phillipson.

Phillipson is a university historian and writer with a fascination for Canadian scientific research. His special interest and insights on NRC flow in part from his major 1970's project to capture the fading fragments of knowledge through tape-recorded interviews. Phillipson explored NRC's major contributions, scientific achievements, and general inventiveness in conversations with retired staff and management. He gained a singular understanding of innovation at the Council on the working level. The interviews slowly pealed back the cover on stories that had not been fully described in the formal histories that cat walked across the high passageways of politics, presidents, and press releases. His research and conversations with others eventually led him to seek out and interview George Klein with whom he filled eight reels of tape.

Phillipson naturally asked questions about the organization-level events, the management, and the major projects, but his questions gradually drew out asides, admissions, and anecdotes from Klein that astounded the historian. A very modest man, Klein always talked about his colleagues first and would say "we did this" or "we designed that" to the point that his vital role was rarely clarified without persistence.

Phillipson is critical and skeptical in his assessment of NRC's history and never willing to base an assertion on limited sources or a single attestation. Yet his research on Canadian science and technology history and his unique experience on the oral history project led him to conclude that Klein was "Possibly the most productive inventor in Canada in the 20th century". He would repeat the superlative and appraisal in the *Canadian Encyclopedia* with the professional bravery that only comes from conviction.

This widely accessible assessment on Klein's career was later noted by journalists and researchers and reinforced in other works and publications.

That Klein could be so recognized and accepted as the country's "most productive inventor" is remarkable in that much of the time the assertions were based only upon his role in large-scale projects such as the ZEEP nuclear reactor, the electric wheelchair, and the space program. Below the surface of these shining achievements, many of which are highlighted and explored in this book, the sea was alive with hundreds, probably thousands, of smaller fish: mechanical devices, techniques, and designs that, amassed, provide an even more compelling image of creativity and invention.

Many forces came together in these inventions. Klein stood at the crossroads of the steady stream of challenges generated by other researchers, industry clients, government agencies, and Canadian society and the support of a tremendous team of technicians, machinists, and engineering staff in the NRC central workshops, instrumentation group, and other labs as well as in his own group. Any list of these latter individuals after so long would be wanting and would undoubtedly omit many worthy names, but it would certainly include Fred Freeth, Superintendent of the NRC shops in the 1940s and 1950s, and Klein's close associates: Doug Baker, Robert Owens, John Freeth, Don Nazzer, Tony Smialowski, and George Mair, many of whom contributed to the major projects cited above.

George Klein's career stands up to Phillipson's assessment and Parkin's account, and there are few who knew Klein that even question the suggestion that he might be his country's most productive inventor if productivity is defined by the quantity of novel and ingenious things that flowed from his mind and were useful to Canada.

One of the most enduring, early influences on Canada
was "Georgian" architecture and design brought by
a large immigration of German Lutherans" over several generations,
and "associated with four Kings of Great Britain,
all named George and all of German descent".[3]

1. THE GEORGIAN ERA

If the crossroads of creativity, the spiritual intersection of art, science, engineering and technology, were to have a geographic location, the Alsace region of Eastern France would fit the purpose well. The Alsace has been the meeting place for distinct cultures and has witnessed the confluence of vigorous societies for many centuries. Resting on the border between Germany and France, it was, of course, worn by the heavy boot steps of armies moving in both directions throughout the late 19th and early 20th centuries. But this shifting back and forth between national interests began, in fact, two millennia ago with the region's conquest by the Roman Legions of Julius Caesar and the subsequent tug of war with the Germanic tribes.[4] Despite being parceled by a variety of lordships, city-states, and fiefdoms in the following centuries, both influences managed to take root and persist within a unique combination as a crucible for innovation and creativity.[5] Even today the ambience of the region's major city, Strasbourg, seems to echo the artistic creativity of Romanic France off of the practical technique of Germany.

The explanation of how this blended history later shaped technological creativity in 20th century Canada and how the footsteps of the Roman soldiers could lead to the surface of the Moon lies in a story that begins with the lives of four men, all named George Klein.

The first began his life as a 19th century Alsatian farmer. The fourth was George Johann Klein, the man who would live to be considered Canada's most productive inventor.

One reason the Alsace managed to maintain its special culture and character was its geographic boundaries: the Vosges mountain range to the west and the Rhine River to the east. Together they created a natural cradle for independence from the central powers of whatever force had most recently conquered the region. This special environment mixed with periods of productive autonomy made it easier for Alsatians to experiment with different ideas including both the Catholic and Protestant expressions of Christianity.

The 16th Century German-speaking Alsatians had their own direct link to the Reformation through Martin Bucer, a prominent Strasbourg figure and contemporary of Martin Luther, who brought Luther's ideas home. It was thus that this part of Catholic France would develop a strain of German-speaking Lutherans, who would withstand many religious wars and contribute to the region's unique personality. The Alsace, therefore, was able to provide a venue for both battlefields and original fields of thought and creation.

It has also seen the cultivation of many, many farmers' fields.

The region is fertile, rich landscape that flows down easterly from the Vosges toward the banks of the Rhine into plains that comprise some of the more productive agricultural land in Europe. The Alsatians have a long history as committed farmers enjoying a favourable environment amplified by the natural sanctuary and feeling of security provided by the mountains and the vast river.

In the late 18th and early 19th Centuries, the region's autonomy and its associated religious tolerance were shaken by the French Revolution, the Napoleonic Wars, and the ensuing, tighter incorporation of Alsace into the governing structure of France. Both the land and its people were considered French property more than ever before.

George I – George the Settler

During this period of unsettling change, two Alsatian Lutheran brothers, George and John Klein, farming near the Strasbourg area town of Melsheim, read about the combined possibilities for freedom and farmland in British North America.[6] The Klein brothers had seen French soldiers harassing women and rounding up other young Alsatian men for conscripted service.[7] Whatever their allegiance to France, they loved their families and way of life more.

Posters distributed throughout Europe in the 1820s and 1830s promoted low cost land in a place called "Upper Canada". The advertising promised "good roads" and other public services and support to settlers wanting to develop their homesteads and live in peace. The posters did not mention snow, the general absence of hospitals and schools or the burdensome conditions for payment to the landowner, the Canada Company.

The Canada Company, an enterprise chartered in England in 1825, was established by John Galt, a Scottish writer and businessman who persuaded a group of British merchant investors of the untapped economic potential in British North America and convinced them to underwrite the purchase of about one million hectares of land from the Government of the colony of Upper Canada. A seemingly enormous piece of this land was offered to the Klein brothers. It was a difficult decision to leave their home and cross the Atlantic, but it was made easier by the knowledge that other German Alsatians were doing the same and would travel with them to start a new life.

Although their 1835 arrival in Upper Canada was bleak confrontation with the wilderness, the blow was tempered by their entourage of countrymen and word that Lutherans from the United States had flooded the region as Loyalists in the wake of the American Revolution. Still other German-speaking immigrants had come to Canada centuries before bringing Georgian era influences to Nova Scotia and Ontario. Mennonites and other German Protestants were also among the waves of Canada Company settlers in the area around the Klein brothers' arrival.

Other nationalities would, of course, contribute to the growth and character of the new land as well. But in the 19th Century, few could match the German-speaking settlers for influence. One group that did was the Scots. Canada's early Prime Ministers were born in Scotland as was the politician and journalist William Lyon Mackenzie, whose leadership of the Reform movement would indelibly mark the history of Upper Canada. Sir Sanford Fleming, early Canada's leading engineer, innovator, scientist and inventor, whose works would include the construction of a transcontinental railway viewed as the country's National Dream and the implementation of an international system for marking time, was also born and raised in Scotland.[8]

Staring back over 200 years of Canadian history and across the life experiences that the two Klein brothers were to engender, it now seems natural to learn that they and their Alsatian comrades shared their trip across the Atlantic to Canada Company lands with a group of practical and inventive Scottish settlers. The Klein family would feel the influence of both cultures in the years ahead.

The Alsatians and Scots were shown a map of the Canada Company lands in Upper Canada and were asked to pick parcels to settle and farm. A line ran through the map followed by the words "Thames River" just like the name of the great, lucrative transportation route running through London, England. Thinking this other Thames might have a similar destiny, they picked land in the area known as the Huron Tract in what is now the Stratford area of Southwestern Ontario. The settlers would be disappointed. Yet despite letdowns over the hollowness of the Canada Company promises, the new settlers persevered to build homes, businesses, and towns.

The Klein brothers, George and John, farmed land outside of what is now the town of Sebringville, in the Township of Downie, Perth County, Ontario. They also started families.

Life was not easy. They were the very first settlers on their particular pieces of land, and they were among the very first pioneers in Perth County. It was remote, rough, and often cold.

George II – George the Milkman

But they had each other. Their farms were on opposite sides of the road, and George, the eldest brother, already in his early twenties when they arrived in Upper Canada, had a wife. Within two years in 1837, she would bear the first of three children, a girl named Mary, followed by Catharina in 1839, and finally a boy in 1842.[9] The boy's name was known at the moment of his birth and had been prescribed many years before. It would be George Klein: the name given to all first-born males in the family line. It was name that settler carried as did his father back in Melsheim, and it would be the name of the baby's future son and eventually a grandson, the great grandson of the settler. This great grandson would be George Johann Klein, the one whose inventions and talent with machines would shape much of Canada's 20th century history.

But first the Klein family history would be shaped by the machines of the 19th century.

Machines and innovative devices were not, initially, a major feature of pioneer life in Upper Canada. It was rugged and minimal. This was most evident when it came to medical treatment. Some of the larger towns had doctors, but usually the pioneers had to treat themselves for serious illness. Midwives delivered babies, and family remedies were the only cures for infections and disease.

Shortly after the birth of her baby boy stresses of pioneer life overtook the young farm wife, and she died. Still in sight of his thirtieth birthday, George Klein, the Alsatian farmer who had crossed an ocean for a new life, became a widower with three children living in near wilderness.

There was no choice. He had to go on for the sake of the three young ones, but he could not do it alone. Although there were few women his age for many miles around, his Scottish neighbour had an unmarried daughter, Elisabeth, known as "Eliza". She spoke Gaelic, seemed quite different, and was some seven years older than the widowed farmer. His three children even knew her as "Grannie McEwan" at the time.

But she was known to be nice, in fact, "a wonderful person".[10]

He considered himself fortunate to be able to remarry within few years.[11] Eliza McEwan would not be able to give the three little children her Scottish blood, but her character, her love, and her family were to become their greatest influences. The name "Grannie" would stick even as she assumed the role of stepmother.

As the years passed, machinery became increasingly important to the Klein family, to all farmers, and to all of Canada. Pioneer farmers yearned for machines. They had special challenges clearing the land, adapting to the severe seasons, and dealing with distances. The development of Canadian farmland would eventually go hand in hand with innovation, and development in farm machine manufacturing, transportation systems, ports, and other features of the urban centres in Canada.

But in the 1840s, few farmers could afford the luxury of owning their own equipment, and they shared a lot to make do. One piece was essential: the threshing machine, the machine that would beat, rub, and remove the grain from the chaff, straw, and husk.

The threshing was usually done in the late fall or early Winter, and the answer most pioneers found was to rent the machine collectively from a travelling, threshing machine owner, and to stage threshing bees. Working together was natural for the farmers. In any case, they had to pool their money, and they had to share their horses because threshing machines took up to eight teams hitched together to power the circular treadmill. As the horses moved around, they would drive a large wooden pulley that engaged a long leather belt in turn driving a small pulley and the pounding thresher.

The threshing bees were fevered work sessions that sought to make the most of the equipment in the shortest period of time.

It was late in the season, in mid-December 1852, when the Alsatian settler George Klein, his then ten-year old son, and the other men and boys of the surrounding farms were working hard to get things done in time for Christmas. The threshing bee that day was going as usual with the horses circling at a steady pace. Suddenly, a noise startled the horses, and they bolted. It was wild and dangerous for everyone. The older George thought quickly and grabbed a rail from a nearby fence reasoning that if he could use it as a lever wedged against the large pulley it would act as a brake on the horses. It would have worked too. But the pulley, whether flawed or unduly stressed, broke apart sending wooden shrapnel into the body of the 39-year-old farmer holding the makeshift lever.

This George Klein, the first in the family to live in Canada, was dead.[12] He was killed instantly, and instantly, the baton of responsibility for the farm, the children, and the Klein family passed under the influence of the Scottish born farm wife Eliza, now in her late forties, and her extended family.

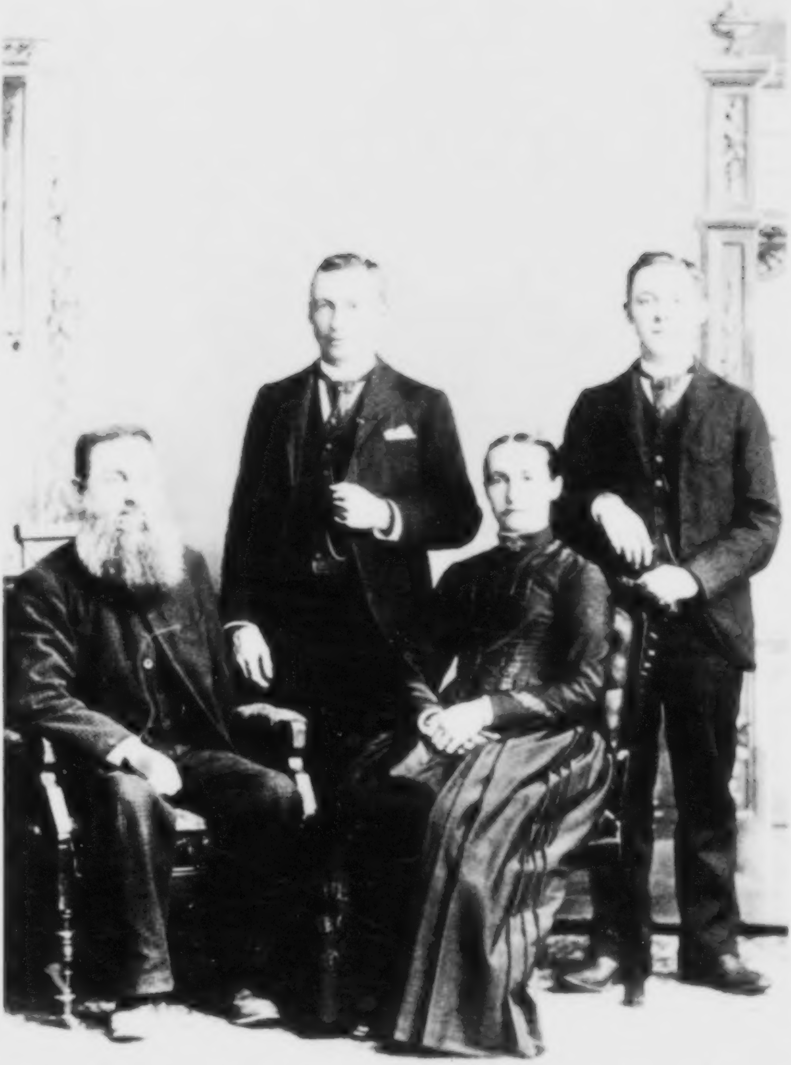
Grannie McEwan raised the children with the strength of their father's story of ingenuity, heroism, and emotion. It was a combination that would be magnified and persist over the next hundred years and be remembered as a tragedy, but also as a story of defective, poorly designed machinery.

The story would be inflamed by other experiences, and sooner than anyone might have feared.

Despite the farm-related death of his father, the second George Klein, the ten-year-old who had witnessed his father's accident, would, nevertheless, grow up as his father and uncle did assuming that he too would be a farmer. It was natural. For most of the 19th century, almost everyone in the land was a farmer.

In 1864, however, when he was twenty-two, his life plans changed. George Klein II was planning his own future and his wedding to young Anna Eve Stoeppler, perhaps thinking about other things, when he made a "dreadful"[13] mistake; one that he had feared for most of his life; one with a pulley on a threshing machine.

This time, it was not horses that acted up; it was the machine itself. The belt fell off the pulley. George grabbed it and quickly slid it back on, but as he did, his hand slipped and got caught in the still whirling pulley. It twisted the young man's entire arm right around so hard, so violently, and so far that before he could be freed, he had injuries that meant he would lose his arm.



George J. Klein's grandfather "George the Milkman" Klein and his wife Anna (seated) and sons George Stepler Klein and John Klein *(Klein family photos).*

The arm was amputated above the elbow and was buried at his father's grave in the Sebringville cemetery.

The pain and suffering under pre-Confederation, pre-anesthetist, rural medicine would fade, but his heartache persisted. His world was shaken to the core by the realization that his life's work had been taken from him along with the lost limb. He could not imagine how to provide for Anna, and he thought he might lose her too. In fact, he tried to break off the wedding not wanting to burden his love with a disabled husband and the millstone of "a man who could not farm".[14]

Fortunately, Anna could see more to her husband-to-be than a certain number of limbs or a specific set of physical capabilities. She fought his attempts to break off the wedding, and they were finally wed at the end of 1867, launching lives together just months after a new country, the Dominion of Canada, was created.[15]

Together, they found a resourceful way to make a living in a farming area without farming, to build a home, and to bring into the world another George Klein, the third to live in Canada and the man who would father the fourth, the great inventor of the same name. Anna and George would see the boy take the name George Stepler Klein[16] with a middle name to honour his mother. He too was destined to have his own run-in with a machine, but it was a much smaller and less physically dangerous one.

First, he would see his father, empowered by his bride's support and optimism, set an inspiring example. He and Anna moved away from the old Klein homestead to start a new life on a five-acre parcel of land slivered off of the family farm. A now disabled former farmer, he had dark days, but some things were going his way. While no time is a good one to lose a limb, George had become an amputee at the height of the U.S. Civil War, a force that produced thousands of disabled and limbless heroes and changed North American society's image of the amputee. The Civil War also pushed industry and innovation forward, both in the U.S. and north of the border, and finally, its consequent military threat had compelled the British North American colonies to join together in the confederation of Canada. One industry that flourished during the Civil War and had enduring impact was the manufacture of wagons and carts. Epitomized by the world leading Studebaker Brothers firm, U.S. and Canadian wagon makers emerged to produce cheaper, more reliable vehicles that were marketed widely.

At the same time, in Canada, the new nation encouraged new opportunity and new thinking.

For the more adventuresome and entrepreneurial German-speaking settlers, it was natural to think first of dairy products. They had brought the knowledge of cheese making with them to Upper Canada, and cheese became one of the common features of the dinner tables in the Huron Tract region. Cheese production would be among the first large-scale businesses in this part of Canada to become enduring expression of the settlers' influence and evolution within their new society. Cheese would become one of Canada's most important industries and exports in the decades ahead.

George II bought himself a wagon and created a business of his own picking up milk at local farms for delivery to the new cheese factory, Ballantyne's, sitting between the road and Black Creek just south of Sebringville.

The Klein family did well from the milk transport business and could even afford one item of rarity for the day: a clock. Clocks were not common in rural 19th century Canada. Even the railways and other transportation systems evaded complete dependency on clocks until the adoption of Standard Time late in the century. Farmers had very little use for timepieces since their days ran from sunrise to sunset with little variation. A farmer who had any extra money for small devices or instruments was more likely to address the burning, relentless need for farm implements and tools. Many things would be found on a farmer's wish list above a clock.

But George J. Klein's grandfather was not a farmer anymore. He was a businessman now, and with routes and schedules to keep, he had a different perspective and different desires. He bought a clock and took great pride in keeping to his schedules. At first, his client farmers would tell the time of day by his arrival for milk pick-up. Later, other farmers in the area would buy their own clocks and set them by the man's arrival.

George III — George the Jeweller

The Klein family clock was a valuable piece in the 1883, and when the clock needed repair, the task of taking it to town was an important responsibility, one that was entrusted to the eldest son, George III, George Stepler Klein. At 14 years of age, he walked down the long dusty road to the town of Stratford and the jeweller's.[17]

"The jeweller" knew about precious things like clocks.

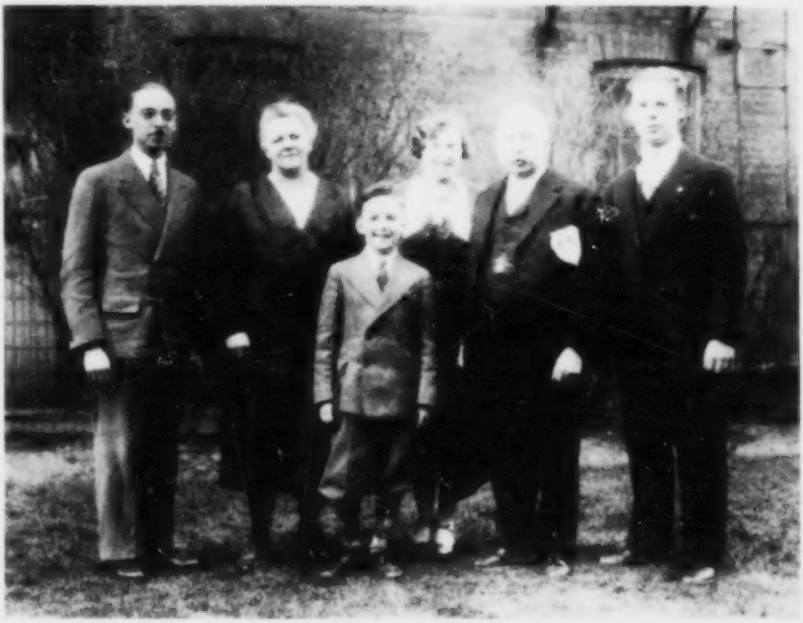
The boy set out on foot around mid-morning, but the hike lasted longer than he expected as he took special care with the delicate and valued device in his arms. He did not arrive at the jewellery store until after noon hour. The store was closed for lunch, but he could not return home without the clock repaired, so he sat on the sidewalk to wait for the jeweller to return. As he waited and waited, other customers would come up to the store, and finding it closed, they left. When the storeowner finally returned, the teenager with the clock told him about all of the business he had missed because the store was closed. The jeweller thought for a moment until he realized that the solution to the problem was staring him the face. He asked the young man if he would come to work at the store during the lunch hours and keep the business open.

He did and was soon working longer hours. It was his first paying job, and he was hooked. The experience sparked a lifelong love affair with the business and particularly the making and repairing of these fascinating small devices, clocks and watches: so delicate, complex, and different from other features of life in the rural area of what was now the Province of Ontario in the new and growing country, Canada.

Eventually his interest in watches and his ambitions grew beyond the limits of the Stratford area. He knew for a long time that he wanted to learn more about the craft of watch making and repair and had even wondered what it might be like to own his own store and business. Canadians were making clocks and watches by this time, but the big centres for study, for those who were truly serious, were still in the U.S. and abroad. In fact, for the most part, the Canadian watchmakers that did exist were still using imported mechanisms or "movements" to build their watches.[18]

Emulating the difficult and daring decision of his immigrant grandfather, the young watch lover left Stratford and his native country to seek a better life. He went to Ohio, a place that had established a special reputation for the watch-making business and education in the late 19th Century.[19] Through experiences that included a side trip to the 1893 Chicago World's Fair, George Stepler Klein would gain a worldliness and a new perspective while living in the U.S. When he returned to Canada as a highly trained watchmaker and "traveller" in the mid-1890s, he knew that he would have to go to the big city to make his mark and his life. Initially, he tried his luck in Toronto with a job that involved a lot of time on the road selling watch movements throughout Eastern Canada.

But George Stepler Klein wanted to settle down, and, by this time, Toronto was not the only big city in the region.



Late 1920s photo of George Stepler Klein (George the Jeweller) and family: (left to right) George Johann, Josephine (Dinkel) Klein, Robert, Marguerite, and (far right) Otto. *(Klein family photos).*

Hamilton was a booming port and industrial centre that had prospered from the U.S. Civil War, railway development, and opening up of Western Canada.[20] Stove and farm equipment foundries, branch plant manufacturing, and the production of pig iron from the Hamilton Blast Furnace Company created jobs, regular paydays, housing construction, and demand for fine things. Despite "Economic Panics" in some years and in some places, Hamilton was a great environment in the late 19th century for someone wanting to start a business.[21]

Just as his ancestors assumed that they would follow their fathers into life on the farm, George Stepler Klein, the watchmaker and the family's third Canadian George Klein, had his amputee father's example as an entrepreneur with a horse and cart as a role model. The terrible accidents had broken the chain of farmers, and the worldly young man would take another step down the different path by opening his own business in the

Turn of the Century James Street, Hamilton location of Klein and Binkley Jewellers, and the first-floor jewellery store *(Klein family photos)*.

city. It was a business that built upon his father's need for a clock and a business that would beat a path between the schedule of an 1870s milk wagon and mechanical innovation in the 20^{th} century.

The business prospects for the watchmaker were magnified in Hamilton where he would encounter kindred spirits and others with similar ambitions. One was named Thomas Binkley.[22]

The two men would see each other as partners and mutual assets, and together they formed Klein and Binkley Jewellers on James Street in Hamilton. It thrived and grew and by the turn of the century, the business was filling three floors of their own building with activity. The first floor on street level was the store; the second floor had the watchmakers and engraving rooms; and the gold and silversmiths who made and repaired jewellery were on the third.

Life was good for "George the Jeweller", and in September 1903, it would become better. He married Josephine Dinkel, a young woman whom he had met in the Hamilton Lutheran Church. The community of the church, the work he had sought most of his life, and the growth of Canada came together in an uncommon zeal.

George IV – George the Inventor

He loved his new bride and loved having someone to not only share his fascination with the gears and machines of the watchmaker's world but to help pass it on. When Josephine was pregnant with their first child, George Stepler Klein purchased a book for her to read in the hope that this might influence the forming aptitudes of the unborn child. She did although she would often say in later years that she was not always sure what the words meant. The book was about mechanical systems.[23]

On August 15, 1904, she gave birth to George Johann Klein: a future inventor and the fourth George Klein in the family to make a life on Canadian soil.[24] His birth was followed by that of a girl, Marguerite (1907) and two boys, Otto (1910) and Robert (1919).[25]

Hamilton at the start of the 19^{th} Century was a good place to grow up.

It was the period of prosperity in Canada when Wilfrid Laurier, the country's first French Canadian Prime Minister, could be re-elected three times in an air of extreme national confidence. Even in this environment that was magnified by dramatic new developments in industry and technology around the world. Hamilton still stood out as an especially lively and thriving town with well-established businesses and new heavy industry.

Hamilton had a population and a permanency by 1904 that meant George Johann would be raised in a community endowed with hospitals, schools, markets, and even a park with a great fountain as well as the hotels, taverns and markets. There were also boot makers, saddlers, druggists, milliners, newspapers, and, early on, watchmakers and jewellers in Hamilton. Hamilton's history and attraction even included a period as the centre for Canadian clock making after the country's first clock manufacturer, the Canada Clock Company, moved there and operated briefly before failing as the Hamilton Clock Company in 1884.

Almost 300 years had passed since the first European footsteps had passed through the area,[26] and early in the 1800s the new "city" had broke through the mark of one thousand citizens. The 19th century railway boom that followed gave Hamilton another boost, and although the city encountered disease, fires, and economic setbacks, it had taken root as a community and was clearly here to stay and an incontrovertible port of importance along the Great Lakes.

George J. Klein's father and his father's friend Thomas Binkley were fortunate to locate their store on James Street, destined to be one the more important routes through the city.[27] James Street was the focus of the early settlement and the first street in the city to, in 1833, get a sidewalk. By the time George Johann Klein arrived in the world, the street was playing a unique role as the civic and cultural centre of the city. The Market Hall, later the City Hall, the Post Office, the Opera House, the Masonic Hall, the Mechanic's Institute and the Armories, all very important civic structures, could be found along its length: magnets for human beings and good for business.

Childhood in Hamilton

Klein and Binkley would prosper and not only produce the means for George to raise his family, but participate in an interesting life.

Settling in Hamilton meant moving away from the rural Perth County of the family homestead, but it was not oceans away, and Josephine's family was near too. Relatives were close enough that the Klein family home at 12 Caroline Street in Hamilton would often welcome visitors, and young George had cousins to play with as well as his sister and two brothers. The house would hold three George Klein's for a while after the widowed grandfather came to stay with the family for his final days playing with children and carrying them around under his only arm.

The large fenced-in back yard was even big enough to play ball, and the basement housed a workshop, tools, and materials that offered an intriguing venue for the boys' amusement.

But the unique gymnasium and studio for creativity and learning that young George Johann had at his avail was access to his father's business. Little George had a natural curiosity about how things worked and how they were made, and he had a wonderful place to exploit it at the Klein and Binkley building. It not only held the mechanical, micro-engineering world of the watchmakers on the second floor, but also the artistic imaginative atmosphere of the gold and silversmiths above.

Goldsmiths, silversmiths, and jewellers had a long tradition that reached back to antiquity and had influenced the evolution of human creativity in many ways. The goldsmith Ghiberti, whose early 15th century masterpiece, the "Gates of Paradise" on the Baptistery at the Duomo cathedral in Florence, remains a source of awe, and is, for example, often credited with launching the Renaissance with its realism, grace, detail, and emotion. A century later, another Florentine goldsmith, one trained as a metalworker, Cellini, would cap off the era with sculptures and writings that made him one of the most intriguing and well known figures of the great period of art.[28] Their profession was perhaps the art form that endured in difficult times because of its practical side.

This practical link blended with experience in precious commodities made it natural for goldsmiths, silversmiths, and jewellers to assume responsibility for handling and marketing early watches and clocks. In addition to the rarity and value of these objects, there were practical matters of designing and adhering bracelets and mounts.

This artistic-style work provided an intriguing backdrop and ambience for visits to the building occupied by the Klein and Binkley enterprise. But the activity that always attracted young George the most was that taking place one floor up from street level: this was the captivating venue for the mechanical work on clocks and watches. George Johann spent a lot to time with the watchmakers asking not only how clocks were put together, but also how they worked together once they were assembled. He wanted to

George J. Klein's 12 Caroline Street boyhood home in Hamilton *(Klein family photos).*

know how the many tiny springs, gears, and pieces of metal could be controlled and continue to perform with precision. It was not enough to merely be able to repeat a process, but he also wanted to know how it was created.

When he came home from the store, he would pour his enthusiasm and new knowledge into the basement where he was "always making something".[29] As a teenager, his basement projects would include sophisticated ventures such the construction of a working-model sailboat almost a metre long with a mast, jib sail, fixed keel, and moveable rudder. George and both of his brothers played with it and sailed it often in Hamilton Harbour. Yet it survived in pristine form, and, some 85 years later, would be seen by descendants as testimony to early signs of cleverness and skill.

George Johann's first use of the basement workshop at 12 Caroline Street, in fact, came many years earlier.

His father, the jeweller, noticed that most of the nails from the workshop had gone missing, and while it was odd, he did not bother to press the matter until a visiting relative caught his pants on a nail climbing over the backyard fence to retrieve a ball. The uncle found that the entire section of fencing was covered with nails. Young George explained that he had been teaching himself to hammer. Although the nailing lessons came to an end at that point, the situation was absorbed with humour and a spirit that would see the incident later celebrated as a positive milestone in a career rather than as a point of recrimination or reproach that might have dampened enthusiasm and inquisitiveness.

His tolerant, pleasant and relatively prosperous home, a father with enthusiasm for the mechanical, the spectacle of the goldsmiths and watchmakers at work, a thriving industrial town, and a country that was growing all combined as George J. Klein's significant early positive influences. But the greatest trends affecting inventive minds were developing beyond his country's borders, particularly to the South. The first decade of the 20th Century was Thomas Edison's heyday. It was the time of the inventor hero when Edison was joined by figures such as Bell, Westinghouse and Marconi in producing marvels that transformed electricity into magical products of use to everyone.

It was also the beginning of human flight.

In 1903, the year before George Klein was born, the Wright Brothers succeeded at Kitty Hawk in making the first, controlled powered flight on record. Word of the achievement spread and encouraged others to develop their own methods and to make their own attempts. By 1908, Canadian Casey Baldwin made a brief flight over a lake in New York State, and a year later. Alexander Graham Bell's Aerial Experiment Association staged this country's first version of the Wright Brother's flight at Baddeck, Nova Scotia with the *Silver Dart*.

Yet this biplane's short journey through the air was not the first concerted, Canadian attempt at human flight.

The previous year in Hamilton, Ontario, a 4-year-old boy, if not aware of the Wright Brothers breakthrough, at least sensing the possibilities, had piled wooden boxes as a step ladder to the top of a fence post where he could perch, arms stretched out as wings. "Mommy, it won't work", he said after his mother came to investigate the noise in the backyard. Little George's initial attempt at human flight would become another in the gently received experiences that amused his parents and hinted at an interesting, developing mind. Three years later, the Canadian who had piloted the *Silver Dart*, J.A.D. McCurdy, came to Hamilton for demonstrations and a contest.

One of those who sought him out and shook his hand was a seven-year-old who would never forget the experience or lose the images of Canada's first humble, biplanes even when technological progress and his life would take his interests and work into outer space. George Johann Klein's childhood had many happy experiences and events that likely contributed to his evolution as a mechanically inclined, inspired personality, but the meeting with McCurdy, the first person to fly a plane in Canada, would be the event Klein himself would point to years later as the most significant.

School and Teenage Troubles

As he grew older, George found increasing opportunities to pursue his growing technical interests at school. School was challenging, and a place for friends, fun, and access to equipment and expertise.

Still, even as a young teenager, George continued to find the family home to be the best place for his most creative and ambitious projects. His interests seemed to have no horizon, and he was drawn to what could be later seen as many engineering disciplines even nascent fields such as the novel new communications device, the radio.

Canadians had a special interest and awareness of the development of radio since Guglielmo Marconi did much of his early work on Canadian soil after having sent the first transatlantic wireless signal from

Teenaged George J. Klein – not a great student, but talented in the workshop *(Klein family photos).*

Newfoundland in 1901. In the first years of the new century, the brilliant Canadian born inventor, Reginald Fessenden, brought new excitement with the first broadcasts of voice and later both voice and music from Brant Rock, Massachusetts.

Amateur broadcasters seized on the technology from the start, and by the outbreak of the Great War, they were already causing interference problems for the military.

One of these "troublemakers" was a young teenager in Hamilton, Ontario.

It was a seemingly ordinary day albeit at the height of World War I when young George's father received a surprise visit by the Hamilton Police at his jewellery store. The very agitated constables wanted the jeweller to come down to their station for questioning. They claimed to have evidence that he was involved in sending coded messages to the enemy. Whether the family's German heritage was cited or not, the police let it be known that they were convinced that the Klein's had some links to German spies and criminal activities.

The police said that they had received word that as far away as Anticosti Island at the mouth of the St. Lawrence river, the authorities had picked up powerful, but coded and indecipherable short wave radio messages. The radio signals were eventually traced to the Klein house at 12 Caroline Street.

The distressed father knew the cause. He explained that his son George was an inventive and creative boy, who been tinkering with radio equipment, and he knew that he was trying to communicate with his friend a few city blocks away. The elder Klein told the police he thought that it was just a toy.

The police escorted the elder Klein home they found the equipment and an antenna hooked up outside of the younger George Johann's bedroom window. While the police were eventually convinced that the radio was merely the work of an unusual boy, they insisted that it was disruptive to security forces and had to be dismantled. They not only confiscated the equipment, but the odd looking antenna as well.

When the Klein family pleaded to keep the boy's invention as just a child's toy, the response was that it was "some powerful toy". It was "some powerful experience" for the young inventor, and notwithstanding the family's customary tolerance and sympathetic humour, this incident was too unnerving for everyone.

World War I was a tense time for Canadians of German heritage. An Ontario Lutheran Minister had been badly beaten by an anti-German crowd; German was no longer spoken in the Lutheran church services; and a frenetic and divisive referendum had changed the name of Berlin, Ontario to Kitchener.

Young George, who would, in the midst of another war 25 years later, joke half-heartedly that his Alsatian heritage made him French not German, was said to have been "terrified". It put a chill into his experimental work.

He resumed his tinkering, testing, and building. This time, however, and for years after, he focused on mechanical rather than electric devices.

Aside from the momentary stress around the "radio incident", the Klein family experience during the First World War was mild in comparison to those of neighbours and friends whose children were old enough to enlist.

George, even as the eldest of the Klein children, was still in his early teens when the streets of Hamilton were flooded with celebration of the Armistice in late 1918. George's only brush with military life came at his school, which was one of the many in Canada that compelled its male students to join army cadets. The scratchy wool uniforms, the ankle-squishing "putties", the marching in cold and heat, and the drills with wooden guns made for enduring, but vaporous and even comic war memories that strengthened, rather than drained, in later years.[30]

Overseas, a generation of young men was gassed, burned, and bulleted. In Canada, the War would change lives and institutions forever. The federal government had been compelled to introduce income taxes, new social programs, and new government bodies including one devoted to the promotion of scientific and industrial research specifically for the war effort, but with longer term economic implications. The provincial school system had also recognized the increasing importance of science and technology within society and the economy.

As the great world and national events unfolded, George, like other teenagers, mostly thought about himself, his schoolwork and his personal future. He struggled as a student. But he passed and would see successes in geometry, chemistry, and physics.[31]

Perhaps, recognizing some relative talent for science and math along with an obvious love for building and tinkering, his parents decided in 1919, when it came time for their son George to advance to high school, that he should enroll in the Hamilton Technical High School.[32] The school offered opportunities to learn drafting, industrial arts, and technical sciences as a complement to mathematics, chemistry, languages, and other traditional studies. The creation of the Institute had been part of the provincial effort to address the needs for skilled trades people, engineers, and technicians in the era of growth and rapid industrial development. While the strains of the Great War impaired some industries, others flourished. Wartime production in novel areas such as aircraft manufacturing magnified interest in science, engineering and technology and meant that jobs for technically skilled students were almost assured.

George's graduation from the Hamilton Technical High in June 1924 was cause for relief if not celebration. It was close. His final report card was sprinkled with many C's which stood for Credit, one step above a failure, and meant a mark that fell somewhere between 50% and 59%.[33]

University Days and the Wind Tunnel Professor

George's academic record did not, therefore, brand him as one of those rare 1920s technical school graduates with great potential destined for post-secondary education. But two forces were working to his advantage and would direct him to university. One was his interest in learning more about how things work. The second was that his family had the means. The jewellery store had survived the stresses of the war and had bounced back as a well-placed business in a town that had an industrial base reinforced by wartime production to share in the eventual prosperity of the 1920s. In 1924, the Klein family could afford the risky experiment of enrolling young George in the School of Practical Science down the road at the University of Toronto.

Staying at home and going to university in Hamilton was not possible in 1924. The city's now respected McMaster University did not exist as an option at the time. Although founded in 1887, McMaster was still, in the 1920s, just a small Baptist educational institution with a different name and located in Toronto awaiting its later move to Hamilton where it would become a full university with private support.[34]

The University of Toronto, on the other hand, had emerged as a strong and cohesive entity after the Great War and was, by the time student Klein arrived in late 1924, a well-established educational institution with a tangle of roots in divinity and theological studies reaching back almost a full century. One of its primary antecedents, King's College, had received its Royal Charter in 1827.

George J. Klein, graduation from University of Toronto (1928) *(Klein family photos)*.

The University was still beaming over its association with Canada's first Nobel Prize awarded in 1923 to Frederick Banting, who proved his concept at the university under University of Toronto professor J.J.R. Macleod. Banting himself may not have recognized it, but the discovery of insulin was symbolic of a new era in research and innovation that demanded the blending of the inspiration and imagination of the inventor with the skills and the dedication of the professional scientist.

In addition to the University of Toronto School of Practical Science, which served would-be engineers such as the young Mr. Klein, the university had well-established schools in disciplines ranging from home economics, education, and social work to forestry, hygiene, and architecture. The University had impressive social, cultural and recreational facilities in the form of the Hart House complex built and donated to the university through the philanthropy of the industrialist, University of Toronto graduate and lecturer, and the man who be the first Canadian-born Governor General, Vincent Massey.

The University of Toronto was, indeed, an impressive place in 1924, and it had the air of both having come far and having places to go. It was not merely exciting for the new student; it was awe-inspiring for the young tinkerer from Hamilton.

George Klein would make friends and meet a number of truly brilliant and exceptional people during his four years at the University of Toronto. Many were fellow students. Klein was, for example, there with the university's first female engineering students including the amazing Elizabeth "Elsie" MacGill, who earned a degree in electrical engineering[35]. The degree, a first for a female in Canada, was only a stepping stone in a career in aeronautical engineering and aviation design filled with achievements magnified not only by gender trailblazing, but also severe physical disability and the confines of a wheelchair. The class of 1928, which included Klein, was close and had a special respect and fondness for their professors. One professor had unusual research interests and an unusual impact on both the physical and intellectual nature of the campus.

Professor John Hamilton Parkin was young, energetic, and, in many ways, a lot like George Klein, but Parkin was old enough and experienced enough to make it easy for students like Klein to keep their distance with deference. Parkin was a committed teacher with one definite principle to be meticulously fair and open with his students. Over half a century later, George Klein would still be referring respectfully to his old professor as "Mr. Parkin" even though the two men would grow to be close friends and true colleagues.

Parkin, born in Toronto in 1891, was already a teenager and starting his studies at the Toronto Technical School when George Klein was born in 1904. As a boy soaked in curiosity and technical aptitude, Parkin had many childhood experiences that would be echoed in Klein's life later: building models, playing with toy imitations of the new innovations of the day, and success in the mathematical and scientific side of school. But Parkin was doing so more than a decade earlier than Klein and when Parkin witnessed the local and world events such as the first airplane flights around Toronto and Hamilton, he did so as an older, more experienced student.

Parkin was not merely motivated by the very early developments in aviation, he was born just soon enough to participate in them. Encouraged by access to copies of *Scientific American* and contest-winning work on airplane models within years of the first powered flights in Canada, Parkin would literally make a life of it. He helped deliver the field of aeronautical research to the scientific world and would live to be known as the "father of aeronautical studies at the National Research Council, and their grandfather at the University of Toronto".[36]

He too studied mechanical engineering at the University of Toronto in the four-year Bachelor of Applied Science program that Klein would also pursue. But by the time George Klein was entering high school, Parkin had not only graduated and gone off for wartime work at the British Acetones Limited plant in Toronto, he had already returned to take advance studies and assume a position on the faculty at his alma mater.

Klein's mentor and friend for over 50 years
John Hamilton Parkin in late 1920s
(NRC Archives).

Parkin's passion for aviation gave him the strength to push, even as a junior faculty member in a junior faculty, successfully for university investments in the thousands of 1920s dollars to eventually construct Canada's second research wind tunnel. It was really the first such facility of significant scale in Canada as its predecessor was a small device built in the New Brunswick workshop and industrial lab of engineer and inventor W.R. Turnbull in 1902. Parkin's wind tunnel at the University of Toronto was large by comparison and not only served academic research, but trained students and served Canada's new aircraft manufacturing industry.

With this device, Parkin was a major force in establishing aerodynamic research and education in Canada. His work was not confined to his own lab and institution. He helped build up a national interest and intellectual infrastructure as a participant on an early 1920s national committee on air research. The Committee included military and civilian experts serving the federal government under the auspices of an Honorary Advisory Council on Scientific and Industrial Research, the predecessor of the National Research Council. The Committee was one of many established to encourage collaboration, information sharing among experts, and the identification of opportunities for investment in research in the national interest. On it, Parkin would make influential and brilliant contacts, such as Group Captain, the later Air Vice-Marshal, E.W. Stedman, that served him well for the rest of his career.

With such influences and Parkin's persistence, the University of Toronto wind tunnel, unique in Canada and one of only a handful in the world, attracted many of the leading figures in the burgeoning Canadian aviation industry. They brought wild stories of exploration and discovery along with intriguing technical challenges. It all combined to create an inspiring environment. It was fun hooked to an exciting, growing industry: aviation.

The wind tunnel was a powerful magnet to bright students, and Parkin amplified the attraction by sharing both the work and any glory with them. One that he came to favour was a not-to-promising arrival of 1924: George J. Klein.

Klein was not simply a user of the university wind tunnel facility, he came to participate in its design helping first to add new and improved balances (measuring and control equipment) to a reconstructed manifestation of the Parkin University of Toronto wind tunnel in 1927.[37] Before his fourth year of undergraduate studies, Klein was already a co-author on research papers with Parkin, including work on international comparisons of the tunnel as well as studies on aircraft components.[38] By the time he entered his final year as a student at the university, Klein was designing and building model planes for novel research projects in the wind tunnel and was being left in charge of "general experimental work" for weeks at a time.[39]

As an educator, Parkin exhibited a strong bias for those who combined academic studies with practical experience. He liked students who had

George J. Klein (third from the right) and friends with 1920s University of Toronto Homecoming parade float *(Klein family photos)*.

worked in mechanics shops as they were more likely to design components or gearing systems that could actually be made in a practical, repeatable way by others.[40]

It was a prejudice that Klein would absorb along with a love of aeronautics, and it was therefore no surprise that when it came time for George Klein to choose a topic for his requisite final-year thesis in 1927, he drew from the aeronautical work. This was still a new academic field and was only just beginning to be recognized as a separate course of study at the university as well as struggling to find its way as a legitimate field of research.

George went home regularly and kept in touch with his family in Hamilton during his university days. For a while, his summer jobs were at the Otis Elevator plant, which was just one of many large industrial enterprises in Hamilton. George enjoyed being close to his family.

But when he graduated with his Bachelor of Applied Science degree in 1928, he chose to be with the research facilities at the university instead.

He did not return home for work in Hamilton industry. He was offered a job that allowed him to stay on at the university in Toronto and to taste an academic teaching career along the path beaten by his mentor Parkin.[41] His title and paid responsibilities were that of "Demonstrator in Machine Design" at the university. It was a position akin to that of a teaching assistant and not truly a research assistantship. But access to the wind tunnel and the opportunity to pursue experimental work on the side was one of the attractions of the job. He would continue to work with "Mr. Parkin" as an increasingly relied-upon resource in the wind tunnel. The 1928–1929 school year was a lot like his previous four at the university, he had to prepare for classes, and his career-related fun came at the wind tunnel where he was glimpsing its potential as a tool to study issues outside the aviation world.

But now he was getting paid.

The aviation industry was growing at a phenomenal pace; even outside the academic world, George's future employment prospects seemed assured. His parents and their business were doing well, and his siblings were proving to be good students. The boys were looking toward university and similar rewarding careers. The world seemed peaceful and prosperous.

It may have felt too good to be true.

The next decade of family and world history would show that it was.

"the only national research facility worldwide that was recognised as a genuine success"[42]
Sir Harold Kroto
1996 Nobel Laureate in Chemistry

2. HELPING BUILD CANADIAN SCIENCE

In the late 1920s, people would go to great lengths to avoid what is now the most prestigious and renowned street in Ottawa.

The street now known as Sussex Drive was in 1929 already the connecting route between downtown and historic residences including Earnscliffe, the former home of Canada's first Prime Minister John A. MacDonald, and Rideau Hall, the official residence of Canada's Governor General.[43]

But these impressive homes stood out, each like an oasis in the midst of old deserted buildings and undeveloped land. The street's eastern end was still little more than a modest, dirt pathway. In the city's early days, in fact, this stretch of road was so rough on wheeled vehicles and their passengers that the Governor General, when compelled to make a ceremonial trip downtown to Parliament, would choose to be transported downhill to a wharf, to board a vessel for a ride down the Ottawa River, and to disembark for another carriage in order to make the short journey to the Hill, rather than ride along the bumpy road that was to evolve into today's ceremonial Sussex Drive route.[44]

In the late 1920s, this roadway was not merely modest, it was a bit of an eyesore and was on Prime Minister William Lyon Mackenzie King's hit list for improvements to the National Capital. Despite the proximity of old-money and mansions, the area bordering the street formed more of an industrial district than a residential area or nationally important locale. There the city's rough logging roots were still evident in a collection of old sawmill buildings, yards, and lots owned variously by the lumber baron MacKay and Edwards families.[45]

At one time, "the whole river front was taken up by the installations of the Edwards Lumber Co".[46] But in the late 1920s, the residual Edwards mill buildings were all clustered at the eastern end near the corner of Sussex and John Street. They would become known simply as "the John Street buildings".

Close by, there was a small hydroelectric plant, built to capture the kinetic energy of Rideau Falls for industry.[47] The Falls are today a sparkling, picturesque termination of the Rideau River; but this was largely hidden beauty. Seventy-five years ago, travelers along the route only heard its noise and glimpsed the rushing water as the Rideau branched and cut under the often-muddy road before pouring into the larger Ottawa River.

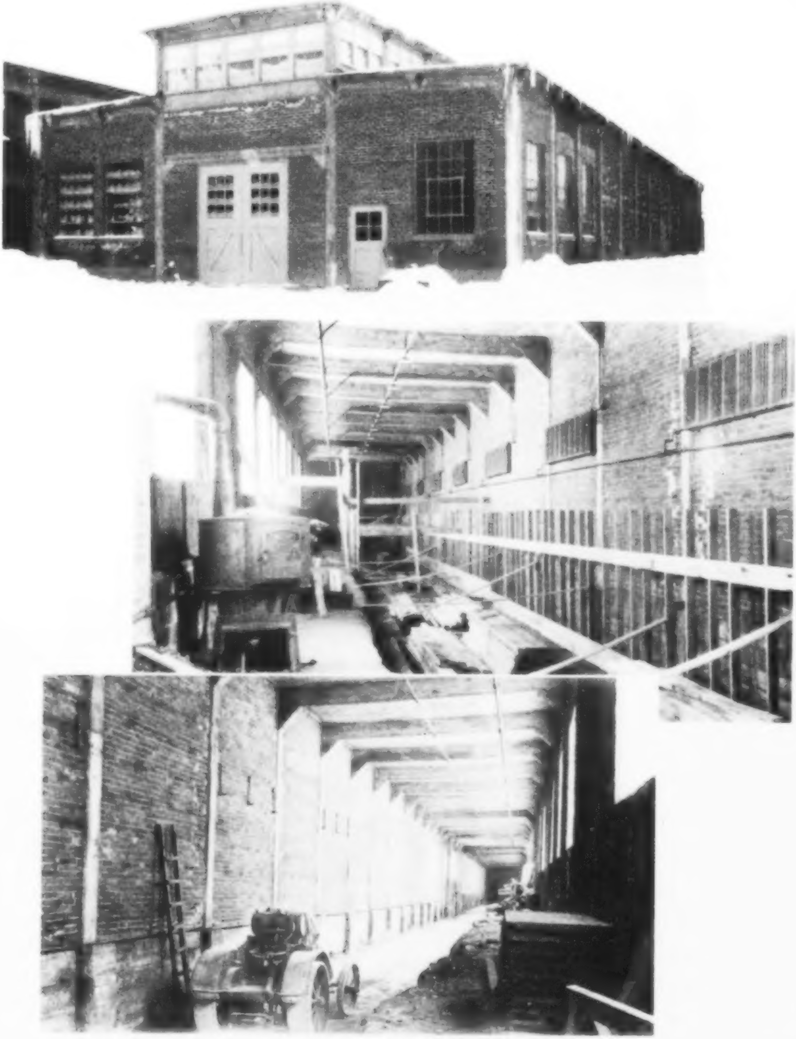
Noise, Mud, and Old Industrial Buildings

Nevertheless, it was this stretch of road and its aging buildings that George Klein sought out as his priority after arriving in Ottawa to take up his new job in September 1929 at the National Research Council. [48] Almost anyone else walking along the road at that time would have found it hard to believe that the area could ever be transformed into an eminent set of addresses and magnet for world renowned personalities. Still, Klein was thinking in those terms when he looked across the road to the river beyond. He had been told of great plans for the area, and he was excited.

Klein had no way of knowing that, within a few years, Earnscliffe would pass from private hands to become the permanent, official home of the British High Commissioner to Canada; that two decades later the large home now identified as 24 Sussex Drive would assume the role of the Prime Minister's residence; that pavement, ornamental streetlights, concrete bridges, and landscaping would follow; and that the area would eventually be augmented by other Ambassadorial homes, by the Ottawa City Hall complex, and by the tiered Lester B. Pearson Building, headquarters of Canada's Department of Foreign Affairs and International Trade. Only those close to Prime Minister King might have guessed that the street was to become, more than anywhere else in the city, a monument to Canada's international influence and interests. The Prime Minister's residence and Rideau Hall would eventually combine with other famous buildings to give the roadway a prominent place in tourist guidebooks and Canadian classroom texts.

These ideas could not have been on 25-year old George Klein's mind as he walked along the street in early September 1929. Yet he would have been imagining great things.

He had been told that the street was to provide an address for a very special building: one dedicated to science. It was one that would attract



The John Street Buildings as they were when Klein arrived in Ottawa in the late 1920s *(NRC Archives)*.

many Nobel Laureates and leading thinkers from around the world. At what is now 100 Sussex, Canada's national laboratories were being planned as the first permanent home for Klein's new employer, NRC, one of the country's newest institutions, but one of its more intriguing. The construction of the building was the centrepiece of the great plans described to Klein that early fall day. His new NRC bosses were wildly enthusiastic, but even they may not have imagined how successful the project would ultimately be.

The building, an architecturally impressive structure dubbed "The Temple of Science" on its opening in 1932, reminds passersby of a model of Buckingham Palace.[49] It would hold teams that were ranked among the world's best, and it would earn recognition as "the undisputed center" for "a whole area of research of general importance". In this regard, it was said to be matched only by "the Cavendish Lab (Cambridge University laboratories that produced much of modern physics) and Bohr's institute in Copenhagen (the international centre for work on atomic physics and the quantum theory)".[50]

Before Klein's retirement 40 years later, a British scientists and future Nobel Laureate would see the institution as "the only national research facility worldwide that was recognised as a genuine success".

The great molecular spectroscopist and Nobel Prize winner Gerhard Herzberg, the science statesman E.W.R. Steacie, and other giants of Canadian research are the figures most associated with these accolades. Herzberg, a distinguished researcher and half century presence in the Sussex Drive building, and Steacie, an NRC President and first Canadian to head the International Council of Scientific Unions, would be among the more celebrated NRC "builders" in the years ahead and those most often credited with the transformation of this part of Sussex Drive.

Yet as much or more than those of any other NRC employee, George Klein's hands helped truly build the first NRC facilities and to establish Sussex Drive as a international centre for scientific discovery and technical invention. In the engineering and physics labs, he literally designed and constructed many of the facilities and equipment himself and later helped pioneer their use.

Klein was, however, destined to never call the grand building at 100 Sussex Drive "home" for his work. He would visit the big building often, but his research days on Sussex Drive were spent assigned to those old abandoned sawmill facilities at the intersection with John Street, the ones he first saw when he arrived in Ottawa.

NRC Builds a Home

In 1929, the NRC was little more than a crystallized idea. Yet it was one that had taken root. The organization's origins are officially traced to that formalized decision by the federal Cabinet to strike an Honorary Advisory Council on Scientific and Industrial Research in 1916. This Council was to act as a vehicle to pull together the country's fragmented and thin research resources during the Great War. They mirrored similar bodies established in Britain a year earlier and responded directly to a request from the British government for a counterpart entity in the Dominion.[51] But well before the outbreak of world war and the invitation from abroad, there had been calls within Canada for a more proactive federal approach to fostering scientific research in Canada. Sir Sandford Fleming, the 19th Century railway engineer and promoter of Standard Time, had called for such an institution decades before, and even industrial interests such as the Canadian Manufacturers' Association had seen a need within Canada's resource-dependent, branch-plant economy for government action to promote competitive research and development strengths.

The Honorary Advisory Council comprised university scientists and a few industry people who might have been expected to advocate for federal investment in their own sectors and interests from their position of influence, and they did. But almost from the beginning of the Council's existence, its members also endorsed a proposal to establish national government laboratories to provide unique-within-Canada facilities that were available to serve all sectors.

These laboratories were to be a venue for a special type of research, the kind that bridged the short-term needs and focus of most industry with the fundamental inquiry that was often the absorption of university scientists. They were envisioned during a period of transition for scientific and industrial research. It was moving from the age of the workshop and lone inventor to the era of professional scientists and teams of researchers. It was a time that called for a blending of skills and new bridges between the two worlds.

National research agencies had been created in Europe and the U.S. decades before. The construction of laboratories as a Canadian "National Research Institute" was seriously advanced shortly after WWI and came close to being a reality in the early 1920s.[52] Yet the requisite legislation failed to pass the final Parliamentary hurdle of Senate approval.

It was not until 1924 that the proponents of the creation of such national laboratories would successfully revisit the issue with the government and see the passage of the first (National) Research Council Act.[53] The Act set down responsibilities for the Council that could only be fulfilled if it had its own laboratories.

In the interim, the Council continued, as it had in its first years, content to attack the shortage of research personnel through grants and scholarships to graduates in universities. The Council also found utility as a force in the national-level coordination of research in selected fields and in the assault on selected issues of national importance through the creation of a number of Associate Committees of experts. The NRC Associate Committees were more than venues for discussion and making contacts. They were empowered by an ostensible mandate from the Cabinet through the Honorary Advisory Council and by some influence over a small slice of the Council's budget.

George Klein knew about some of the Council's growing pains. As a student at the University of Toronto, he was aware of the Council's Associate Committees because his professor, "Mr. Parkin", sat as one of the founding members on the Committee formed around aviation research. Klein also knew of the Council's role in funding research at universities. It provided useful money for construction of the Parkin wind tunnel at University of Toronto and a number of the research projects conducted in it.[54]

As he approached graduation in 1928, Klein became increasingly involved in research at University of Toronto. The 1920s were an exciting time for aeronautical research in Canada, and Klein thrived on it. But his talents were not restricted to this one area of application. He was becoming known for his general ability in mechanical design, and it was for this skill, not his work in the wind tunnel, that he earned his permanent job as a Demonstrator.

Klein would gain new insights into the relationships between different fields of research, a hint of his potential as an innovator outside of aeronautics, and a first opportunity to step out of his professor's shadow. But this would take another year.

The Demonstrator position at the university was not a true a research post even though Parkin considered Klein to be both "a research assistant" and "an instructor" at the University of Toronto.[55] In any case, Klein's decision to remain at the university as a "demonstrator" and to teach would, in the end, form a launch pad for his life-long career in research and engineering design.

Despite his awareness of the Council's funding role and its special contribution to University of Toronto engineering research, Klein would not have known about the organizational and administrative developments at the Council during the fall of 1928. He was beginning his first year of full-time work as a university graduate and had other things on his mind than the political and bureaucratic wrangles up in Ottawa. But he would soon learn of them first hand.

In October 1928, the governing council of the body — that was by then being called, officially, the National Research Council — met to take the first steps toward establishing its permanent, in-house research program. It was already looking ahead and had received government approval in the form of a $750,000 construction budget for the Sussex laboratories. The governing Council, now acting as much like a board of directors of a research institution as an advisor to government or mere source of funds, met in Ottawa to commit to the creation of operational programs: a Division of Research Information and three research divisions, initially called *Industrial Chemistry, Economic Biology and Agriculture*, and *Physics and Engineering*. Each was to be led by a "Director", a position that the academics around the table saw as similar to the "Chairmanship" of a university department. But, as his choice of Divisional names suggests, the President of NRC, H.M. Tory, felt his research Directors should also be capable of working closely with industrial partners and, in this context, he also anticipated the need for someone to lead mechanical engineering work. This person would obviously have responsibility for the increasingly important field of aeronautical research too.

When the enthusiastic and persistent H.M. Tory was appointed as full-time President of the Council in 1928, he was clearly up to the task of building an institution. A McGill professor of varied interests, he went West in his youth to help found the Universities of British Columbia and Alberta, the latter of which he led prior to coming to Ottawa. Even in his seventies, after leaving NRC, he would go on to help create Carleton University in Ottawa. H.M. Tory had a broad knowledge and understanding of the state of Canadian research, universities and personalities.

With this backdrop, the NRC President not only recognized the importance of aeronautical research, he also recognized that there was really only

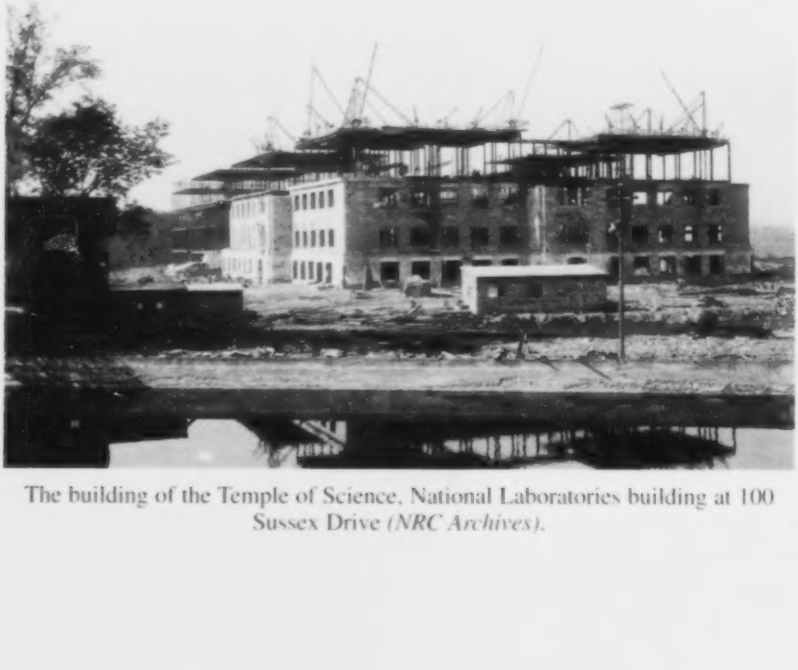
Mud and noise along what is now the Sussex Drive ceremonial route in Ottawa circa 1930 *(NRC Archives)*.

one candidate for the job at NRC: the University of Toronto "wind tunnel professor" John Hamilton Parkin.

Parkin was courted by the NRC almost from the point that the need for aeronautical research laboratories had been identified. His appointment was fast-tracked as much as possible, but it was not until the summer of the next year that Parkin would be in Ottawa planning his first moves. He felt allegiance to Toronto in many ways, but could also see the possibilities in the National Capital, and he took the plunge.

It was the early summer of 1929 when Parkin formally accepted the appointment as Assistant Director in the Division of Physics, ostensibly under the Director, Robert William Boyle.[56] Parkin's slightly more junior position and title may have been created as a way of freeing him from certain administrative burdens. In any case, it allowed him to focus on the two-pronged responsibility of supervising research and overseeing the design and construction of new engineering facilities that would include, of course, a next generation national-scale wind tunnel. Parkin would also have a special challenge because he and his staff were being assigned to the old mill buildings at John Street.

The first priority for Parkin, the Division of Physics, and the National Research Council was the hiring of good people. The new laboratory facilities at 100 Sussex Drive, designed as a monument-like ode to neoclassical architecture, would include excellent facilities and space. But in 1929, the completion of the new building was still several years away. There was a lot of manual and technical work that needed to be done in the interim in order to prepare for the big building. The immediate need was not for world-leading scientists, but people who could make best use of the old



The building of the Temple of Science, National Laboratories building at 100 Sussex Drive *(NRC Archives)*.

sawmill buildings sitting at the far end of the NRC property just east of the Falls.

Tory, Boyle, and Parkin knew that they needed a special breed, it was not enough to hire bright university graduates with high marks and a flair for research. They needed people who were creative in a practical sense and were willing to get their hands dirty.[57]

Tory and his Directors wanted people who could see the link between the aging, industrial facilities and the vision for scientific exploration that could alter Canada's future and its role in the world.

The first person they hired for the new research divisions in Ottawa was George Klein.[58]

A Leap of Faith

Parkin had known that back in Toronto, the young graduate had already taken his first steps toward becoming a true colleague of his old professor. Klein stayed on in Parkin's wind tunnel and even saw his name as co-author on more of Parkin's research papers during the 1928–1929 school year. When Parkin accepted his new post in Ottawa and left Toronto, he had enough confidence in Klein to recommend that the former student lead a special research project at the university in his stead.

This work, a study of windmills, was for a University of Saskatchewan professor named Greig and was funded coincidentally by the new National Research Council. The project began in May 1929, the month before Parkin's departure for the National Capital, but it would last over the summer of 1929.[59]

The research produced useful, basic information on the design of windmill blades. It showed, for example, that even in very modest winds of 12 to 13 kilometres per hour, if the windmill blades were made just right, the windmill "will begin to charge a 6 volt battery". This would be known decades later as "the cut-in speed" of an energy producing windmill, and the attainment of such a low "cut-in speed" would still be considered "good" for a wind turbine even in the early 21st Century.[60]

The project was exciting and memorable for Klein, the young graduate, and would still be influential over 40 years later. At the time, it was significant because it imprinted on the young inventor's mind that wind tunnel research had a much broader potential than he originally thought. In the decades since, wind tunnels at NRC have helped advance technologies for all forms of transportation from submarines to race cars and have been used for clothing design and developing equipment for Olympic athletes. But in 1929, the wind tunnel was still seen, almost exclusively in some circles, as a tool for the aviation industry. In testing the prairie professor's theories, Klein did most of the experimental work and even designed the model windmills and measuring equipment.

He also learned to turn, twist, and tune the windmill blades with an elegant skill that stuck and would soon serve him well in confronting other challenges.

Before the windmill project was complete and just before he could mark his 25th birthday, George Klein was told about the opportunity to work under Parkin in Ottawa. Parkin was keen to have his energetic and hard-working former student with him. He had seen many bright students at the University of Toronto including others in Klein's 1928 class, but there was something about George Klein's attitude and skill that made him stand out and worthy of this special recruitment. Klein accepted, and, again, emulating Parkin took the leap and moved to Ottawa.

Parkin returned to Toronto in the first week of September 1929 to settle his personal affairs and finalize arrangements around the sale of his Toronto home and move to Ottawa. When he drove back to Ottawa, he brought his former student with him to take up the position as the first-ever full-time researcher at the NRC.

The drive back along the old "Highway" from Toronto to Ottawa gave the two men lots of time to talk. In fact, more time than expected. The Parkin family car broke down and had to be repaired along the way. The repairs were mishandled at a garage, and the car broke down a second and final time just outside of Ottawa. Mechanical problems thus compelled two men destined to be among the country's top mechanical engineers to make the last leg of their momentous trip to Ottawa in a bus. The Parkin car was a box-shaped 490 Chev.[61]

For the rest of his life, Klein would be known as a "Ford Man", who drove his new cars with pride and care, but never wavered in his loyalty to the brand and the dealer (the long running Campbell Ford of Ottawa) nor did he ever bother to engage his mechanical skills and knowledge in the process of car buying. He just went down to the dealer's and bought a new Ford when the time came to get a replacement.

Indeed, Parkin had much to talk about on the car-bus trip and later at the Parkin family's temporary home across the River in the Kingsmere Lake area of Quebec where Klein stayed for a short time after his arrival in Ottawa. Parkin described the Council as a dynamic place powered by the President's drive and fueled by Government funding. It was as if a floodgate had been blown apart. The decade of waiting to begin laboratory research, the false starts, and finally strong funding approval created an energized atmosphere. The launch of construction on the big building on Sussex Drive, first-rate appointments to the Director positions, and the mandate to seek out good people for the labs and shops made for heady times.

Tory, the former University of Alberta President, did not wait for new Ottawa lab space to begin work. He initiated the first research programs in biological sciences with university teams in Edmonton under Robert Newton, the first Director of this division.

In Ottawa, Parkin had been given the first research employee in part to help in the task of rehabilitating the old John Street buildings. The assignment could have been disappointing or even insulting to others. But Parkin was not unhappy.

Notwithstanding the great size and the grandeur of the planned building at 100 Sussex Drive, Parkin was not impressed. As a taxpayer, he would have liked it built in stages with wings and rooms added as needed and as the research effort grew. As a mechanical engineer, he was disappointed to see that the plans for the new National Laboratories did not include space or other provisions for design and fabrication shops, something he had come to consider as essential to any effective engineering research operation.

He and others were confused by the government's choice of a downtown location and would have preferred something like the Department of Agriculture's Experimental Farm in the Southern part of the city. The grand nature of the Sussex laboratories with its hand-painted ceilings, ornate carvings, and winding staircases would later make Parkin and many scientists uncomfortable. This discomfort would be magnified in lean years ahead. There was no such feeling of awkwardness at the John Street labs.

A Good Job in a Good Place during the Depression

The start of the Sussex building project approaching $1 million, the creation of NRC laboratories, and the rapid hiring of "good people" without going through the Civil Service Commission were all decisions taken only months before the October 1929 Stock Market crash that launched the Great Depression. Almost literally, Klein's appointment and the decisions that would define his career and much of his personal life slipped under the wire before the curtain of restraint, cutbacks, and freezes fell.

Klein was appointed with the title "Junior Research Physicist" to be part of Parkin's new mechanical engineering group. The NRC Division of Physics did not offer the option of the more apt title of "Junior Research Engineer" at the time. A 25-year-old armed with a mere undergraduate degree in applied science, Klein was joining three distinguished research Directors, the President, and his administrators.

Klein's job came an annual salary of $2,100, less than a third of what the Division Directors were being paid, but a good salary, and about $300 per year more than he might have expected. The second appointee to the Division, K.F. Tupper, a man with seemingly equal qualifications (a former student of Parkin's, a university degree and modest real world experience) was appointed at a lower level as Senior Draughtsman at only $1,800 annually. That Tupper, a future NRC Vice-President, was highly regarded was clear because Parkin went to considerable effort to bring this other former student back from Calgary to work for him in Ottawa. Other early recruits included the talented J.J. Green, the first employee with a Ph.D., and M.S. Kuhring, the largely self-taught, high school drop out whose instinct and commitment to engine research would see him lead teams and rise to the highest scientific professional positions at the Council.

There were many impressive members in the core team. Yet Parkin must have seen some special value in Klein.

The extra $300.00 he awarded him was appreciated and would prove very useful.

The Depression took a few years to truly hit Ottawa. There was a period of denial fuelled by the assumption in senior government and political circles that the economic downturn would pass. In fact, it was not until 1932 and after the NRC Sussex laboratories were complete that the impact of the crunch was fully felt and acknowledged in the National Capital. The King Liberal government would lose power partly as a function of this attitude.

In the mid-1930s, when special capital construction projects were reintroduced by the R.B. Bennett Conservatives to combat unemployment, Ottawa benefited again.

George Klein had chosen about the best place in Canada to weather the Great Depression. Hamilton, his hometown built upon industries aimed at consumer markets, however, did much worse, and his family had its own special strains.

The jewellery store and watch-making entreprise that had prospered so well in the boom times for almost three decades was the first to be burned by the economic collapse. Luxury items such as rings, necklaces, and watches were among the first purchases to be scratched off every family's shopping list as fathers were laid off, mortgages were foreclosed, and food lines grew.

George's father could see the flood of red ink coming, but was determined to fight. He had some capital and stock built up and could have applied it to his own well-being or a scaled-down business. But he used it instead to maintain operations and employment for all of his loyal employees.

It was hard on the family though. There was no money for anything extraordinary and the times had changed a lot from five years earlier when George had enjoyed special support as the first child heading to university. Now, as the eldest and one with a government job, George was positioned to pay back the debt to his family.

He began a practice that would last many years: sending money home. He would methodically and consistently slice a generous tithe from his NRC paycheck to help his siblings pursue studies at university. His sister Marguerite had finished high school by 1929, was in her twenties, and was already in the working world when the Depression hit. She would eventually spend 40 years working in administration at the Hamilton Board of Education. Bob, the youngest, was just entering high school.

But George's eldest brother, Otto, was approaching his 20th birthday and the same age that George was when he began university. Otto too was seized by technical challenges and the influence of the watchmakers, and he too wanted to pursue an engineering degree. With George's financial help and model to follow, Otto graduated from the University of Toronto, became a professional engineer, became a specialist in metallurgy, returned home to Hamilton, and helped champion innovations at the city's premier employer, Stelco, the former Steel Company of Canada.[63]

He also continued the practice. He, Otto, also passed the baton of education along to the youngest brother Bob helping him through school. By the time, Bob's turn came money was even tighter and he would work for a year before attending university, but with his brothers' help, he would pursue a career as an aeronautical engineer. Bob joined de Havilland Canada, eventually becoming Chief of Airworthiness at the firm that brought many advancements to Canadian aviation.

The Klein family pulled together throughout the 1930s. George went home often and did what he could to help. The investments in each other's education would pay off in many ways and be an important force in helping them all move on with life.

One benefit was the creation of a mutually supportive base of appreciation for innovation and engineering ideas that would continue for over half a century. The three engineers and their families would get together often and talk with great volume and enthusiasm. For George, it would be an adult version of the fun atmosphere around the basement workshop projects, model making, and tinkering of his youth.

Sawmills Become Scientific Facilities

Despite Ottawa's favoured status, by the mid-1930s, the Depression was starting to have an impact in life there too. But when he was in Ottawa, Klein's mind was diverted from bad news by the excitement of the work.

Klein never had a chance to dwell on any unpleasant circumstances around his new job. Almost at the instant that Parkin explained that their engineering labs would be housed, not in the planned palace down the street, but somewhere within the chaotic collection of old buildings between the Falls and John Street, he also told young George that one of those old buildings would someday contain many facilities better than anything the two men had used or even seen before.

They could, Parkin said, rival the very best such facilities in the world and would only be constrained by the size of the buildings and their combined imaginations.

Klein loved the challenge and the opportunity.

There turned out to be more of both than he expected. The challenges began with the unexpected state of disrepair of the buildings.

Parkin and Klein recognized immediately that the buildings were not pretty and would need a lot of work. They also knew that designing and building ambitiously large and innovative research facilities would be a challenge in the best of locations. But they could not have predicted many of the hurdles before them.

They soon learned that there were no architectural drawings or plans to consult. Only the hazy memory of former mill workers offered any references for inferring what they might find behind the walls and below the floors. The preliminary work became an exercise in what was later called "industrial archaeology".[64] They discovered that the visible structures were, in fact, third generation buildings constructed upon the remains of demolished or fire damaged predecessors. In one spot, close to a cliff over looking the river, the buildings were balancing on top of a bed of sawdust.[65]

The old buildings, the demands of a new organization, and the technical issues involved in designing unique and internationally competitive research equipment suited the 25-year-old Klein just fine. He was said to be "in his element",[66] and he would remember the next decade of his life as the most fun, productive, and rewarding of his career even though his greatest achievements and most noteworthy work would come later.

It was a great environment for talented and enthusiastic people. They were building a new institution that had yet to resolve itself around the limitations of the real world budgets and government constraints. The imagination, the perceived national needs, and the motivation of technical challenges defined the atmosphere of daily work. The times were tough, but for those who had jobs that they liked, their good fortune was enhanced by a feeling of gratitude and duty to those on the food lines.

Even though the permanent residents of Ottawa were largely insulated from the full impact of the Depression, they were not oblivious to what Parkin and others would recall as ghastly and horrible times for the country. In addition to budget reductions, hiring freezes, and salary cuts, the evidence of the general crunch was also seen when the Department of National Defence and the Royal Canadian Air Force stopped sending staff on assignments for training and research at the new NRC facilities.

The NRC was gearing up the old mill buildings on John Street and opening a magnificent new building down Sussex Drive. But it lacked staff.

The Council had been created to be a special entity that bridged between the worlds of academe and the private sector and government, and with this concept in mind, those drafting the legislative and administrative tools to create it decided to give it special human resource management flexibility including the capacity to hire outside the authority of the Civil Service Commission. It was with this authority that Klein had been recruited, hired, and put on the job without advertizing, competition, or expense. He was hired because of who he was and who knew him. Criteria that worked well for Klein, his lab, and ultimately for Canada in this instance, but perhaps not sustainable within the larger system of the federal public service.

It was in this context of flexibility and need that the Council's early managers, all new to Ottawa, had the temerity to seek the approval to bring unpaid employees on staff during the Depression. The blessings were given, and many young men, brilliant in many cases, well-educated in all, were allowed to work with Klein and his colleagues in the new national laboratories only for the right to gain experience and have something meaningful, instructive, and enriching to do with their days. They were expected to keep the same hours, follow the same rules, and meet the same basic requirements as the paid staff. They were denied days off if it did not fit with work plans or if it was not for permissible reasons. Their numbers were limited, and their terms at the Council were finite.

Labourers in the so-called "relief" work camps were treated better in many ways.

Yet the Council could not accommodate all of the truly qualified applicants for the "slave" labour positions. Some pleaded in vain for the opportunity to work for free.

It was frustrating for Parkin and other managers not to have the means to reward or compensate these men and women, but opening the labs to them seemed the right thing to do. It helped exploit the public investment in the facilities and give life to them.

Working with these unpaid colleagues augmented the existing sense of gratitude and dedication in Klein and those other paid employees who managed to come on board prior to the Depression became fully apparent. Klein's feeling of being privileged in his work and job would stick with him for many years.

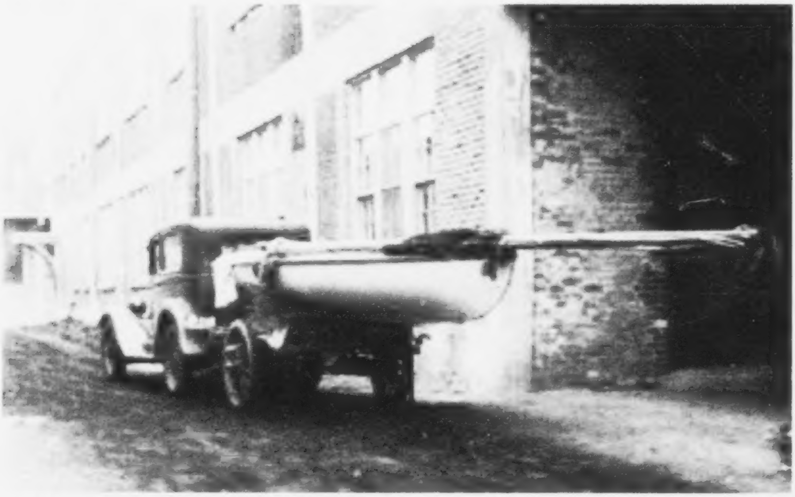
Klein was "full of beans" during those days. His co-workers were friends as well as colleagues and young. Parkin, still in his thirties, was considered the "old man", but despite his "advanced" age managed to attend many meetings in pubs and parties. They worked long hours, but many were single and the lines between work and personal lives were blurred and sometimes missing. Klein, who was an accomplished violinist and would be at times a member of symphony orchestras in Ottawa and Hamilton, practiced music with co-workers for relaxation.

During this time, he took his childhood passion for tinkering and building as expressed in his masterful model sailboat to an adult level by building a full-scale sailboat in his spare time. Living with one private room in an Ottawa boarding house, he was compelled to undertake the project in one of the empty spaces at the John Street mill-building site. Many days he literally never left his place of work.

Indeed, real work would often require long nights and weekends at the labs. First, the overtime was required in response to the demands of the growing and competitive aviation industry, later it would be under the pressures of a coming war and its aftermath.

Klein was young, inexperienced and clearly the junior member when among Parkin and the other Directors. But he had a special status that was apparent from the beginning. Until minimal renovations could be made to mill buildings on John Street, the only base of operations for Klein's then Division, Physics and Engineering, was a small cottage across the street at 83 Sussex. The Director Boyle, Parkin, and Klein shared it with a few clerks, messengers, and secretarial staff.[67]

It was cramped, but was never fully vacated until the main building at 100 Sussex was opened in 1932. Yet Klein was luckier than his later colleagues like Tupper, Green, and Kurhing who would be told that their workspace was the unfinished, unlit John Street buildings for the first part of the 1930s.



Taking the Klein designed and built sail boat from the John Street labs in the 1930s *(Klein family photos).*

Next generation aeronautical research was clearly a top priority for the Division's engineering teams reflecting Parkin's interests and the directions he and NRC had received from the Associate Committee on aeronautical research. But the NRC and Parkin knew that aviation would not be the only industry that they would serve and that they would need other tools. Plans were also in the works for facilities for testing aircraft engines, fuels, oil burners, and machines. The labs were to have shops and drafting rooms as well as some office space.

All of the facilities demanded a certain amount of patience and ingenuity.

Ships, Boats, and Floats Invade Sussex Drive

But one that posed a special challenge was the design and construction of Canada's first national-scale marine testing basin, a long tank to tow models of marine equipment and vessels. The marine test facilities had been given a top priority.

Canada's shipbuilding and design industry, despite Depression era setbacks, was large enough to warrant such a facility alone, but the need had been magnified by the growth of bush flying and air transport requiring floats and pontoons.

The first problem facing Klein and his colleagues was the fact that not one of the John Street buildings was big enough for a suitable wave tank.[68] The tank had to be a specific minimum length in order to conduct adequate research and tests. Constructing new facilities or lengthening one of the existing buildings seemed prohibitive in cost and counter to the intent of taking advantage of these existing structures.

So, they did the only thing they could. They stuck two of the buildings together.

Klein and his colleagues took the bizarre step of essentially sealing themselves in. At the archway entrance to the John Street sawmill site, they knocked down the concrete and brick walls of two lumber sheds on the opposing sides and built a passage to join them together.[69] The result was one long building some 120 metres (400 feet) long that ran right along the Sussex Drive side.[70]

Another route was found into the John Street site, and the need for a long building was addressed.

But this was only a small part of the design challenges in front of them.

The entire project was made tremendously complicated by the vision for a new kind of marine test basin capable of dealing with aviation issues. This was not negotiable. The Council and its Associate Committee, in fact, soon saw the planned marine tank primarily as a tool to develop and test pontoons and floats for aircraft

These special problems were, like many others in the decades to come, given to Klein.

When testing floats for aircraft, researchers need to move the models down the tank at speeds that were the highest possible, reached as quickly as possible, and maintained as consistent as possible. The requirements were significantly different from what had previously been used in other countries in testing for ships or standard marine structures.

The answers required ingenuity and original approaches. But Klein and his colleague Tupper had little time to think if they were going to influence the basic design and construction of the towing tank. They were told that because of budget issues the equipment had to be ordered and the concrete for the basin had to be poured by the end of the Fiscal Year, in other words, before early spring 1930. For many months, Klein was acting barely one step ahead of construction crews and was considering costly approaches that were not only novel to him, but were new to the research world.

NRC would need something totally different from the conventional drive systems used for ship testing basins. The customary approach involved the use of a heavy car that suspended the models underneath and brought them along as it crawled down the tank. The drive was driven by an electric motor and moved with limited acceleration and low traction on wet rails. A researcher would add more weight to the machine riding on top to record data and make observations.

Klein knew he would have to design and build the lightest possible car he could. The first thing he did was to throw the rider overboard.

He did so by developing an entirely new device to record data on a paper around a drum automatically. A kind of mechanical computer, the papered drum was rotated by the wheel of the car as the whole system moved down the rails on the sides of the tank. This novel data collection system eliminated the need for an observer on the car and thus extra weight.

Klein also wondered whether there was really a need for a motor, at least for a drive system that moved up and down the tank on top of his measurement system. Instead of a heavy motor on the car, Klein's system would pull the car down the tank with long cables reeled in by a motor

Old sawmill buildings that became world-class laboratories *(NRC Archives)*.

fixed at one end of the basin. It not only managed the acceleration better than the old systems; it reached speeds faster. Precisely what was needed for aircraft float research.

Klein and his team attacked the design and construction of their new machinery with exceptional dedication and thoroughness. They, for example, ground the railheads to an amazing-for-the-times degree of consistency of ".0025 inches".

These innovations worked. They gave Klein the speed and consistency that he needed, but they also gave him new headaches.

Because cables tend to stretch and warp as they are moved around, left hanging or engaged abruptly, Klein found that the parameters of the experiments and comparability of results would be jeopardized by using cables as a core element of the system.

He wanted to keep the system and its cables so he came up with a way to baby them and ensure that they did not stretch. Klein's team designed and built special, long wooden cradles to carry the cables around and to protect them. They also designed and built a novel system to automatically control the car through the start, acceleration, run, deceleration, and stop. These tight controls would protect the cables and other parts of the system from unnecessary stresses.

Together it was a package of dependable devices that could move models at the high speeds over the distances they wanted. Better in some ways than other towing tanks, but this meant that it was also better at making waves. Surges in the water after tests in the tank could still be measured the next day.

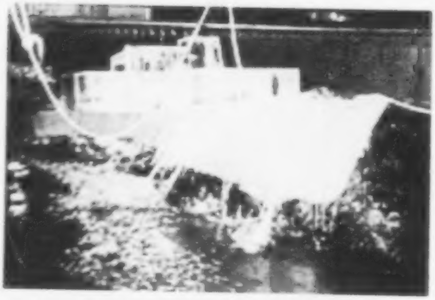
This would be unacceptable for a facility under heavy demand as the water had to be returned to pristine stillness before measurable test runs could be conducted. The waits after fast runs of model airplane floats would make the facility impractical.

Klein and the team dealt with this problem in the same way as nature kills waves: on "beaches". They directed the construction crews to run long thin beach-like slopes along both sides of the towing tank with no rims or walls on them. The small angle of the slopes would gently dissipate modest waves, and large waves would send water over the sides rather than flowing back into the tank. On the other side of the beach edges, Klein hung a wooden trough to catch the excess, big-wave water so it could be returned to the tank in a slow orderly way by a sump pump stationed at the end of the basin.

There were a few glitches in the early years. Leaks appeared in the tank, but it turned out to be not a function of the novel design, but rather due to the recurrent problem with outside workmanship. Parkin would later refer to such problems simply as "government concrete". In 1931, when unexpected low temperatures changed the viscosity of the oil, the car ran completely off the rails at the end of the basin causing significant damage. Changes were made, and both problems were resolved.

A riderless towing car, precision approaching a thousandth of an inch, beaches on the towing tank, and a drum and paper data collection system. It was much more than a long dirty swimming pool. Klein was very proud of his numerous innovations and excited when the preliminary trials began in the wave tank.

Tupper eventually took over the refinement of the marine towing tank and research in it. Klein would move on to other projects, and become better known for his contributions to different fields. Canada's first significant marine dynamics test facility would rarely rate a mention in any listing of his life achievements. Yet, there in the first years of the 1930s in the old sawmill on Sussex Drive, Klein left a footprint in the water as one of the pioneers of marine dynamics research in Canada sending out ripples that have brushed up against naval architecture and ocean engineering across Canada and internationally.



Today's marine dynamics research at NRC Institute for Ocean Technology in St. John's, Newfoundland *(NRC)*.

As planned, the NRC towing tank was indeed used during its early days in the development of aircraft floats for the military and special purpose planes, but it the context of world war, it would turn out to be more important as a facility for the design of boats, ships, and other marine structures.

Its first major project, in fact, was neither a ship nor a plane. It involved work related to the locks and canals of the early St. Lawrence River system. It was slightly ironic that this initial work would contribute to the development of the St. Lawrence transportation route destined to eventually supplant the Rideau Canal which was marking its 100th anniversary in 1932.

Part of the broad development of Upper Canada that embraced the Klein family, the Rideau system helped make Ottawa attractive as a site for the national capital and institutions that eventually included NRC. Still, work for the St. Lawrence system seemed fitting as a natural evolution in the development of engineering technology in Canada which, in many ways, started with the construction of the Rideau Canal.

A World Class Wind Tunnel in a Working Class Building

There were lots of things to do during those years. Just helping Parkin decide what the best use of the site would be, what buildings should be used for what, what repairs were needed, and what equipment should be ordered would have been enough to occupy many people. But Klein was constantly attracted to mechanical problems that not only taxed the brains, but the hands. There were small, likely dozens if not hundreds, of unrecorded tasks of this kind during this period.

But one project would be fully documented and would link many ideas and provide enduring visible testimony to Klein's early work. It was one that was most heard and seen, and it was the one mentioned first after he had been hired as NRC's first researcher: the wind tunnel.

The President of NRC had authorized work on the wind tunnel with a matter of weeks after Klein's arrival in Ottawa. Construction work began in tandem with the towing tank and other work a couple of months later. Again, Klein and the design team kept just one step ahead of the construction crews.

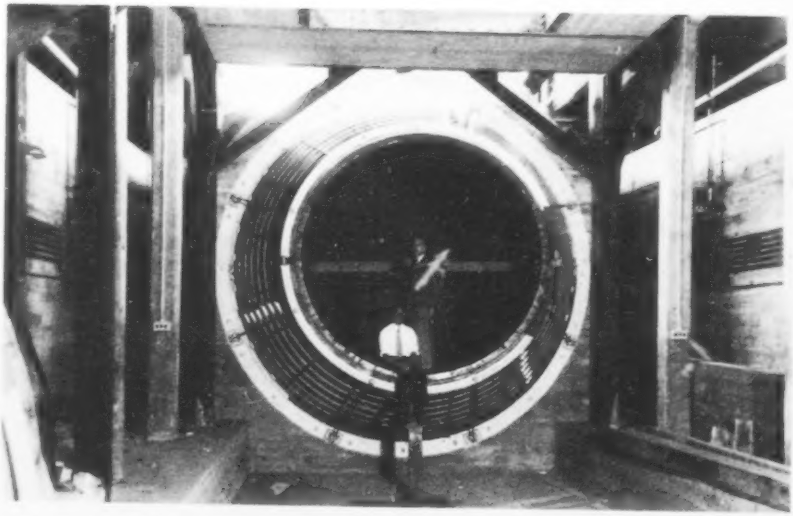
Just as it seemed when Klein first came to the Capital, the project would, indeed, be limited only by his imagination and the physical constraints of the John Street buildings. The former was unfettered, but the latter constituted a significant constraint. The chosen building was a lumber shed "140 feet long and 50 feet wide". The roof rose to a maximum height of "25 feet", but it was only "17 ½ feet high" at the eves.[71] This meant that the square that contained the propeller and air collection tube of the tunnel could only be about "17 feet in height".

Although this would be the first such wind tunnel in Canada and significantly larger than the one Klein had used in Toronto, wind tunnels had become quite common throughout the industrialized world by this time. They could be found not only in national aeronautical laboratories, but also universities and even in industrial labs.

They had been built in makeshift facilities before, and there were approaches and experiences to build upon. One of the requirements of any chosen design for facilities at the John Street buildings would be efficiency and power economy. The generating system at Rideau Falls, the source of power for the NRC labs, was not only influenced by the natural, seasonal variations in water flow, but also by the seemingly uncontrollable and, to Parkin, irresponsible decisions of the lock keepers up the River at the Hog's Back Falls south of the City.

The situation called for a European design known as the "Göttingen" type: an open jet wind tunnel with a closed air return system. It was economical with respect to use of power and would fit into the long shed.

The design was named for the University of Göttingen[72] where German Physicist Ludwig Prandtl started theoretical work in 1901 and later pioneered, sophisticated wind tunnel research that would earn him recognition as the Father of Aerodynamics. An aeronautical research wind tunnel can be viewed as a very simple device that produces a stream of air and directs it at a model of an aircraft or other object in a way that allows people to measure the impact of the air on the model.



Scientist J.J. Green (standing) and Klein in the John Street Wind Tunnel during construction *(NRC Archives)*.

In the early years of the 20th Century, the Wright Brothers and others managed to put themselves above the pack of would-be aviators by simply using a crude wind tunnel that consisted of a fan sending air down a tube that tapered into a nozzle directed at the model. The air would then dissipate into a larger area and an "open-end". Some early wind tunnels were only a foot or so in diameter, but soon researchers realized that bigger tunnels meant bigger models and bigger winds. This meant less correction for scale and more reliable research results.

But as they grew, the downsides of this design grew as well. It got more and more difficult to control the pressure, temperature, humidity and other variables during experiments as the air blew around at differing speeds and from differing directions.

The closed-circuit Göttingen design chosen by Klein for his wind tunnel not only helped combat these outside influences, it also saved energy. In this design, the air is still, of course, blown through the test area and over the model, but it is contained within the building and sent back around with fans in a loop.

With this basic design, Klein had what was, by 1929, a well-established concept to build on, he had his own experiences, and he had his mentor

Parkin, a man who had not only pioneered wind tunnel research at the University of Toronto, but had also toured the world's best facilities in his first year at NRC. Klein also had special challenges.

He had to work with an old rectangular building that did not lend itself to the smooth circular circuit design most attractive to early closed-return wind tunnel builders.

Although air speed is not everything in wind tunnel research, it is one measure of the facility's overall capacity, and Klein and his contemporaries were striving for greater and greater speeds in their wind tunnel designs. The pursuit of this goal was complicated by the need for an intricate system of fans in the old building that could, in turn, be distorted by the heat and effect of the higher speed air streams.

A water-cooling system could reduce the temperatures of the recycled air. But the question was how and where such a system could be installed in a way that did not interfere with the airflow.

Klein's wind tunnel building was fairly big, and it would allow Klein to design a larger facility than most. Indeed, Parkin recognized that it would be one of the bigger ones in the world. But the John Street lumber shed was just a bit too small for Klein and his colleagues to strive to make their mark through size alone.

The length of the building was as much of a constraint as the height since the tunnel would need to taper into a bell collector and nozzle area in a precise manner to be a useful scientific device. The result was that the nozzle diameter would be limited to "9 feet". This was the defining characteristic of the facility as it was the measurement that decided the scale of models that researchers could use in it, and the "9 foot wind tunnel" would be the label that described its relative size.

With these basic characteristics prescribed by the available facilities and choice of general shape, the opportunity to construct any kind of competitive wind tunnel would have to come in the details of design, craftsmanship, and precision in making the components used in the facility. Klein's fingerprints and personality would be all over these many features of the project.

In the execution of the construction work, Klein was able to easily conceive of what had to be done and convey that information to his technical colleagues at the NRC. Together they were even able to describe in engineering drawings and specifications that suited their purposes.

Their renderings of Klein's vision bordered on works of art as much as architecture. They had to describe the subtle transition from a square, box-like room down to a progressively smaller circle and tube. It was an odd looking structure even viewed from just one angle and from outside. But it was even more complex when considered in three dimensions and from the inside out. It was a totally frustrating concept for the laborers and construction teams from the Department of Works. They had never encountered anything like this project before.

Even their seemingly good-natured boss, the Clerk of Works Frank Ross,[73] had no idea how to approach the task, which may have struck him and his staff as something akin to shipbuilding with concrete.

The impasse was broken when Klein called upon a skill he developed as a teenager and would recall throughout his professional life. He made a model.

Klein made a cardboard model on a scale of 1:12 that both showed how the forms should be made for the exterior and how the inside of the nozzle should look.

The cardboard wind tunnel and Ross became good friends. He carried it around under his arm throughout the project and used it to check work and identify problems.

With the help of such interventions, the basic construction work was nearing completion by late 1930, barely a year after the start of Klein's design work. Klein was already starting to think about the component systems and had lots of ideas. He was accustomed at the University of Toronto to having access to first-rate support in the laboratory mechanical shops. At NRC too, a strong, technically competent team was being assembled.

But the Depression put a freeze on hiring at the NRC, and the few staff in the shops were under growing pressure to assist other laboratories and faced greater strain with the imminent opening of the "big building" down Sussex Drive.

Klein was compelled to do a lot of the shop and instrument work himself in order to get the job done. This approach was precisely the quality NRC management had sought when they hired Klein in 1929, but the question of what Klein might have been able to achieve with greater human support during those years is intriguing to consider, particularly in light of what was achieved.

Klein made many noteworthy contributions to the finalized wind tunnel including the design and demanding construction of the aerodynamic balances. Balances are a set of instruments and devices that combine to measure the lift, drag, pitching, and yawing of an aircraft model in given conditions and wind speeds. They are vital to wind tunnel research, and their efficiency and dependability are essential. Klein's special contribution to the balances not only included building them, but devising a new placement system. He put them on top of massive concrete platforms above the air stream.[74]

With this system, the balances could be moved on cars, but the massive platforms made them solid and less vulnerable to vibrations of motors and machines.

The novel approach even struck the old wind tunnel expert Parkin as worthy of special note, but in general, Klein's work on the balances was characterized more by diligence than design.

He would instead show special creativity in his approach to the other major technical challenge: the shape and configuration of the vanes that directed the blowing air within the tunnel and during experiments. The square building using the Göttingen design meant directing the wind along straight walls, through right angle corners, and back into mid-tunnel. It would increase the distance the air traveled and would add to the challenges of achieving a set speed. This task of directing the wind was performed by the blade-like metal vanes.

Klein knew early on that the only way to construct a rectangular tunnel that cycled the air back around would be to use a series of fans augmented by a system of special turning vanes that could direct and control the speed in a consistent, smooth and predictable way around corners.

The velocity of the air can, of course, be controlled in such a facility by changing the speed of the rotating fans, but is also influenced by the angle of the fan blades.

Possibly emboldened by his success with windmill blades, Klein convinced his colleagues that he could devise more efficient vanes to direct the wind in the corners of the air passages.[75] He wanted to study not only the profile of the vane, but the spacing and incidence.

But how could one conduct research, test and development a new wind tunnel device without a completed wind tunnel? The typical Klein response was chosen: he built another small-scale model wind tunnel and then tried out metal vanes of various sizes, shapes, and thickness. Klein and his colleagues not only determined the most efficient corner vane system, they also discovered that it was possible to use thicker vanes without a major increase in resistance and without affecting the overall speed of the wind tunnel. This meant that he could create an entirely new type of wind tunnel vane: one thick enough, for example, to carry cooling water that would ensure consistency in the face of higher speed winds.

This model wind tunnel would turn out the first true research from the John Street facility and would produce the first research paper.[76] It was an influential paper reaching far beyond the very small audience of wind tunnel makers. It was said to have "practical industrial applications in the design of corners or elbows in water, steam and air ducts or other passages".[77] It was many inventions in one and would be applied in many ways in many places. Klein was now committed to finishing off the wind tunnel.

Pressures for more research and the demands from the aviation sector helped to push the schedule ahead, and thus, in mid-1931, the wind tunnel facility was given its trial runs.

It worked, and it worked exceedingly well. With the Klein innovations and improvements, the wind tunnel went beyond virtually all of its design specifications. A shortage of staff and other resources meant that the team could not conduct exhaustive trials or spend a lot of time on fine adjustments the might have improved the test results. Nevertheless, it was duly recorded that the "maximum air speed was 150 miles per hour at 1000 rpm of propeller, with a power consumption of 600 horsepower … these figures indicated a power factor of 0.38 which placed the tunnel among the two or three most efficient wind tunnels in operation. In ability to approach full scale conditions the tunnel ranked fifth, and in maximum air speed, second" in the world.[78]

The rankings would make it an internationally competitive facility, and a great boon to the John Street labs coming into service a full year ahead of the big building at 100 Sussex. Klein and others would keep the wind tunnel operational and improving for decades. In spite of an explosion in aeronautical research and research facilities in the 1930s and 1940s, the modest wind tunnel building along Ottawa's Sussex Drive at John Street would still be worthy of mention in standard textbooks over a decade and a half later.[79]

By the early 1930's the National Advisory Committee on Aeronautics (NACA) in the U.S. (the forerunner of NASA) had two powerful wind tunnels at Langley Virginia, with top speeds "around 120 mph" and by the mid 1930's an "8 ft diameter high speed tunnel (500 mph)". The University of

Klein taking flying lessons and sitting in his office during the 1930s *(Klein family photos).*

Detroit had a "150 mph 7 by 10 ft". tunnel described in the magazine Aircraft Engineering in 1931, the same year as the trial runs at the NRC's John Street facility. In the United Kingdom at the Royal Aeronautical Establishment at Farnborough, there was a gigantic for the times "24 ft diameter tunnel (speed only 115 mph)"; some time before 1936 and later a "5 ft diameter (215 mph) tunnel".

There was a lot of competition around, and even the "power factor" efficiency of the John Street wind tunnel would eventually become commonplace among most return circuit tunnels of the 1930's.[80]

What made the Klein's John Street wind tunnel special was its combination of strengths: speed, acceleration, and power. It was a combination that not only showed an exceptional achievement for the old facilities and the times, but it put NRC in a position to meet the uniquely Canadian needs of bush pilots and a fledgling Canadian aircraft industry. There was a lot of work waiting to be done on Canadian problems from the design of equipment used in aerial surveys to the way to attach a canoe to a plane.

The excitement was intense as Klein, Parkin, Tupper, and others felt the air rush through the channels and blow around their new facility. They knew and could see the work ahead. Research, testing, and tinkering with models and aircraft components was already waiting to be done. They could also imagine the impact they might have on the exploding Canadian aviation industry. They knew they had a powerful tool and a world-class facility. But they could not have known that soon all of Canada and the world would know it too.

And they would probably never have guessed that this recognition would come for work that few of them would have recognized as being their field.

Dark Days and the Dawn of Discovery

The atmosphere excitement, invention, and discovery in the labs at NRC contrasted with the darkness surrounding life back in Hamilton. George visited Hamilton often during those years. But times were tense in the home he remembered as lively and uplifting for most of his life.

The Depression and lack of business ate away at the jewellery store until it finally collapsed in 1937. The end must have seemed cruel and abrupt for some people as Klein's father kept all of the employees on staff until he could not keep any of them.

His wife, George Johann's mother, had a serious mental breakdown that year, and soon after, her husband, the elder George Klein, George Stepler Klein, the jeweler and businessman who, as a teenager, had taken the family clock down a dusty road to town back in another century, died.

With his father dead, his mother in hospital, and the family business gone, the young George needed his government researcher job more than ever. He and his brothers vowed not to lose the Klein home in Hamilton and began sending back more money to cover the taxes and maintenance costs to ensure that their mother had a house when she would surely recover. She would eventually come home, but impaired, and George and his brothers would continue the practice of sending a portion of their salaries to Hamilton for much of their lives.

The year 1937 was a taxing time for George for sure, and he may have wondered how so much could have been lost so fast. But he was an adult. Thirty-three, healthy and unscathed by war, the depression, or disease that hit some, Klein was grounded in a career that strengthened his creative soul as well as his bank account. The contrast of these facts with the extreme misfortune in the world around him mollified his losses, and he pressed on with life.

Meanwhile work at the NRC laboratories was moving ahead full steam, and the fruit from some seeds planted there on John Street were starting to ripen.

There was already talk of the need for new and even better facilities for his group. In 1935, a new President, the scientist-soldier Andrew McNaughton arrived at NRC after the abrupt non-reappointment of H.M. Tory. General McNaughton, a verified inventor of the cathode ray direction finder — a precursor of Radar and the artillery commander whose scientific approach made a crucial difference in the WWI victory at Vimy Ridge, was someone who appreciated the value of practical, technical skills and solutions and would over the next decade become quite familiar with George Klein and his work.

Shortly after McNaugthon's appointment, the predictable decision was made to sever Parkin and his engineers from the Division of Physics creating a separate Division of Mechanical Engineering. Also in 1936, the French Embassy was opened on Sussex Drive right across the street from the John Street labs. The Embassy featured a wall of large windows giving the Ambassador and those close to him a full view of the old concrete and lumber that enclosed the NRC aeronautical and marine engineering labs.

Within months, word came from higher levels in the Government that there would be support despite the tight economic times for moving the NRC engineers to another locale, for removing their old sawmill buildings, and for developing the space across from the Embassy as a park. The park was not built immediately and, in fact, the old buildings would still be standing there a decade later. But Parkin seized on the invitation to move, and powered by McNaughton's sense of looming war, a plan was developed that would eventually see NRC's main aeronautical engineering facilities and, indeed, main research presence move to a large campus on Montreal Road around the Rockcliffe airbase just outside of the eastern limits of late 1930s Ottawa.

Klein eventually would move too.

He would, in fact, play a large part in the inventions, the designs, and the work on two other, newer wind tunnels at what came to be known as the NRC Montreal Road campus.[81] In many ways, he would end the 1930s as he started them, inventing and designing innovative research facilities, tools, and equipment for others.

But first, before the move and the great events that surrounded it, he and his colleagues would realize their first research successes working in the their full size wind tunnel in the old buildings at John Street and Sussex Drive.

Full view of John Street Laboratory buildings in 1940's with the Embassy of France and the Prime Ministers residence in the background *(Defence Research and Development Canada).*

The Wind Tunnel and the World's Fair

It was not the largest wind tunnel in the world, but it was close. It may not have been the most powerful and efficient, but given its circumstances it may have been the best it could be, and although not the fastest, it was very, very close. The combined excellence in so many features made it a unique and potent tool for supporting Canadian innovation.

It turned out to be just the instrument that an important Canadian industry needed in the early 1930s, the one that defined the nation in the 19th Century: the railways. The Depression had decimated cargo traffic from many, many sectors, and erased orders for new rail equipment and the Canadian jobs that the railways embodied.

Yet Canadian National Railways (CNR) officials were not expecting answers that would turn around business when they came to the NRC wind tunnel staff in June 1931. They were concerned more about safety.

The railway engineers were complaining about a recurring problem with the smoke from the stacks of their steam locomotives. The smoke would flow back across the cabin in a way that completely obscured the driver's vision making him nearly helpless in the situation. Even the smoke would clear with a change in speed, the difficulty and time it would take to try out different speeds made it impractical and likely impossible to just manoeuvre the smoke away.

They were looking for some permanent fixture or device that could be developed or devised with blowing smoke tests in the NRC's heralded new research facility. Although Klein would collaborate on the project and be a major influence through the use of his facility, he was not the only one involved.[82] In fact, the lead in the train project was given to Dr. J.J. Green, the Ph.D. scientist who arrived at the aeronautical lab a year after Klein and a year before the Canadian National came calling. Green, a graduate of Imperial College and London University with research experience in aeronautics, had been a little frustrated by the workshop atmosphere at NRC and the lack of basic research in the early days. He would take the opportunity of the CNR request to attack the project from first principles and even from a theoretical perspective.

The problem had many intertwined causes. More and more tunnels and bridges along rail routes limited the height of the smoke stacks on locomotives, and when travelling at low speeds or cruising with little exhaust, the smoke would not be thrown high enough in the air to clear the cab.

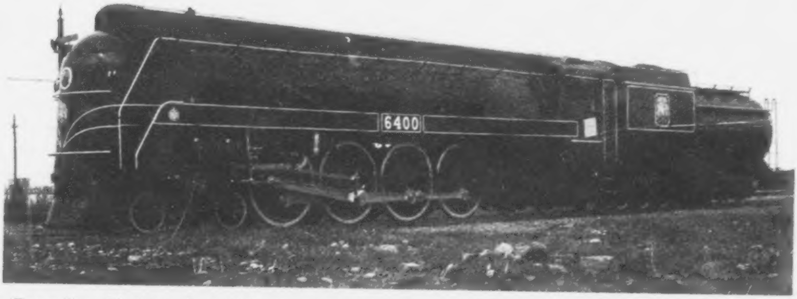
The task, therefore, was more complex than merely testing out models until the researchers found one that did not carry the smoke back on the cabin at any speed. NRC could not, obviously, recommend the elimination of bridges, tunnels, and low speeds nor could it prescribe the removal of legally required safety equipment: the bells, whistle, lights, and access ladders. The railway engineers also told Green, Klein, and their colleagues that a new design would of no use if it did not allow easy access to working parts, axle boxes, connecting rods, valves, and gears.

And, at the same time, the vital measuring instruments, notably the balances, had not yet been completed in the wind tunnel.

The researcher's hands were tied a bit, but not cut off.

They went to work. First, they devised an arduous, but effective system of manual measurement, observation, and calculation to compensate for the lack of instruments. Next they tested models provided by the railway to establish baseline measurements for comparison and that went well. The initial tests produced interesting results including the basis of a formula for predicting wind resistance for a given model at a given speed. Then, the scientists were ready to propose and test their own ideas. They tried many.

A full range of possibilities were tried out hoping now not only to solve the smoke problem, but to improve the overall design and efficiency of the locomotives. Slowly, better and better approaches were developed until an entirely new external form for steam locomotives emerged from the lab. It not only got rid of the smoke and lived with all of the railway's safety and maintenance constraints, it had an overall air resistance some 33% less than



Canadian National's 6400 class semi-streamlined locomotive built in 1936 using the NRC design *(Canada Science and Technology Museum)*.

the models formally in use by the railways. The results were published in the Volume 8 of the new *Canadian Journal of Research* in January 1933.[83] Patents for were filed and marketed around the world by the NRC. But they were made available free of charge to the CNR.

Changing locomotive shops around and deciding to invest in the manufacture of a new series of locomotives does not happen overnight even at the best of times. Yet the CNR was convinced, and the height of the Depression, it started work on a new generation of steam locomotives at the Montreal Locomotive works using the NRC design over the next few years.

In 1936, Canadian National unveiled five new 6400 series steam engines "with considerable fanfare" celebrating "their distinctively modern look" and their "semi-streamlined" NRC design. The railway hoped that the slick design would not only reduce air resistance and cut costs, but it would attract travellers. The engines were therefore put to work in the passenger service, first in Southern Ontario and later throughout the system and eventually other railways were adopting similar designs.

It was a marketing coup for CNR, and the railway took full advantage of it in its advertizing and promotion in Canada, the U.S. and abroad.

Meanwhile, the word was spreading in the scientific and engineering world as well. Requests for photos and information came from the U.S., Europe, and the Far East. The reports on the train design were reproduced in other Journals and technical publications. Klein's novel wind tunnel in the old sawmill building off Sussex Drive, still only a toddler with baby teeth, had made a name for itself.

The NRC did not have the capacity to fight big U.S. railways in patent infringement cases, but it took note of the sequence of publishing, patenting, promotion, and then adoption of the design by the Americans in the years that followed the project.

Finally and predictably, Canada's other railway came knocking on NRC's door as well. At first, the Canadian Pacific Railway (CPR) engineers resisted seeking help from the aviation researchers in Ottawa, but their management directed them to do so. The engineers may have been suspect of the efficiency and even safety benefits of the design, but their President and his management saw the impact the streamlined locomotive engines had had on marketing and promotion for the passenger services. The CPR soon had its own NRC-design type locomotives in production and later in service.

Early promotion of the NRC-influenced steam engines spoke of "semi-streamlined" locomotives as the term streamlined had been restricted in other uses to a very specific shape. Technically, it is a teardrop in some applications. But an adventuresome "advertising man" used the addition of some arbitrary new features on the CPR locomotives to justify the use the term "streamlined", and it was thus that the NRC wind tunnel researchers became linked with what were among the world's first streamlined steam locomotives.[84]

The success of the wind tunnel in this and other projects came in tandem with improvements in Klein's personal life. A regular and active, if not attentive, attendee of the Lutheran Church throughout his life, Klein had developed a circle of younger friends outside of work through church groups in Ottawa.

One of the prettier, more down to earth, and interesting members of the group was the future Florence Klein. Florence and George began dating, playing tennis together, and exploring Ottawa as a couple in 1938 although they had met as members of the larger group around church a few years earlier. The family tragedies of 1937 and the frequent trips back to Hamilton may have delayed his recognition of the opportunity.

Florence Elizabeth Schrie came from Pembroke, a one-time lumber town up the Ottawa River, where she was a bright student and finished high school with lots of promise. But it was the 1930s, and there were few jobs even for men willing to lift heavy things, live in logging camps, and risk their lives. The best Florence could do to keep her spirits and mind alive at first was to continue coming to school helping out in the office for free and, like the unpaid graduates at NRC, for experience.

One day the Civil Service officials came through Pembroke to administer the annual screening examination for potential federal government employees. Florence was there, unpaid and eager, to take the exam again. She passed and was offered a job with the Division of Statistics. It was like winning the lottery.

"Florence has a job with the federal government down in Ottawa, don't you know?"

It did not make the front pages, but it was big news for her friends and family. She would hold onto government jobs until October 1940 when she married, and as required by the policies of the day, relinquished her job and started making a home for her interesting and sometimes frustrating creator and inventor of a husband. She would give birth to a boy, naturally another George, and a girl, Maggie, over the next decade.

Florence and George, the budding engineer-inventor, were courting within an interesting environment. Ottawa was, of course, the country's Capital City, and this meant a regular parade of important figures passing through town.

This gave George at least one opportunity to brag about the wind tunnel designed, streamlined locomotive.

The CNR's 6400's and the CPR's streamlined Hudson class steam locomotives were both chosen to pull the Royal train carrying King George VI and his wife, Queen Elizabeth, over major portions of the Royal couple's popular and internationally promoted, cross-Canada tour in 1939. The CPR trains would be later known as the Royal Hudsons. One of the most publicized phases of the journey was their trip to Ottawa where everyone turned out, and George was positioned to impress his bride-to-be with the story of how his work was carrying the Royals across Canada.

George Klein and bride Florence (Schrie) with wedding party October 1940 *(Klein family photos).*

Meanwhile, the publicity for the NRC train design had reached a crescendo that same year when one of the CNR locomotives was featured at the World's Fair in New York City, the futuristic exposition that inspired Walt Disney. It was an internationally celebrated event that history would remember for the public unveiling of television, nylon, and other revolutionary innovations that defined the 20th century.

The fruits of Canada's new national laboratories, its humble wind tunnel on John Street, and George Klein's ingenuity stood proudly in the midst of this great showcase for human creativity.

Still, Klein did not receive much personal attention for this work. After all, the investment, manufacture, and use of the locomotives was due to decisions and actions taken by the railways, and the publicity was a function of their advertizing minds. The fundamental, published research was led by J.J. Green who thoroughly understood the aerodynamics and could see its application to locomotive design.

The role played by George Klein was in devising the unique novel and ingenious tools for the research and to guide their use. He would play this part many times in his career. Klein had, in fact, moved on to other ideas, to other challenges, and to dozens of other projects. Throughout the 1930s, the John Streets labs became increasingly busy and in demand. The staff worked on many of the country's most important early aircraft and produced a string of components. Marine transportation problems ranged from ship hull designs to hydrofoils and barges. Klein, as one of the core engineering team, had a hand in many solutions. His contributions would be novel machinery, engineering designs, or innovations that helped others.

Before the end of the decade, his skills would be called upon to help meet the varied, urgent pressures of war.

But first, he would start work on the very Canadian concern, one that linked frozen rivers and lakes to exploration and adventure.

"sometimes the sliding resistance of the skis is so great that it is impossible to reach flying speed ... other times, skis adhere to such an extent that the (propeller) thrust is not sufficient to start (the plane) sliding".[85]

3. THE SCIENCE OF SKIS IN THE SKY

Look at a map of Canada. A map from the early part of the last century would be best, but a more recent one will still do.

The intensity of dots and lines along the borders and the shorelines at the bottom contrast with great empty expanses elsewhere. Canada is, obviously, still a lightly populated country for its size. Its people and infrastructure are concentrated in the South with roadways embracing a comparatively small part of its landmass. Even in the 21st century, most of the physical country is not accessible by road or rail.

Fortunately, Canada also has tens of thousands of small lakes and rivers: natural runways for airplanes equipped with floats in summer or with skis in winter.

Canada also has lots of winter.

These easy observations, combined with the knowledge that Canada has grown as a function of natural resources discovered and developed in remote locations, hint at the national significance of the design and study of aircraft skis.

Even modest improvements in the efficiency and safety of aircraft skis would produce tremendous benefits for Canada. Making it possible or even just practical to use them in more conditions and in more places would have an influence on history.

In the first of half of the 20th century, few people in the world, if any, had more impact on the scientific study and design of aircraft skis than George Klein.

He made many crucial discoveries, applied his insights to the aircraft that defined bush flying in Canada, and provided the basis for such ski design around the world. His work on aircraft skis helped open up vast areas of Canada and likely saved lives.

Aircraft Skis before Klein

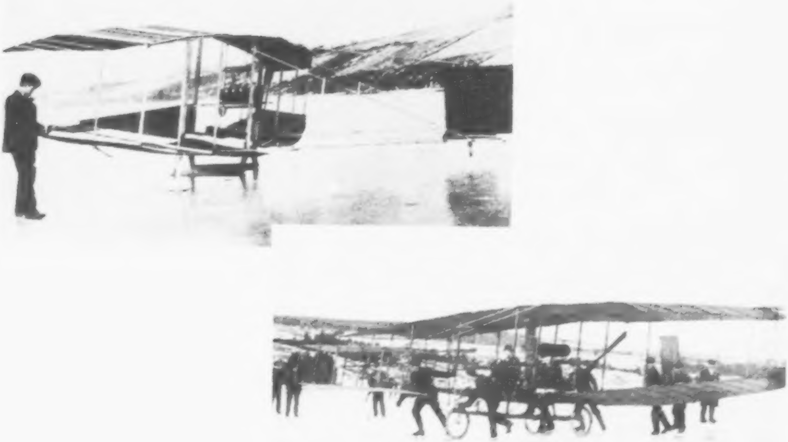
The notion of winter flying has, however, been a part of Canadian aviation history from the very beginning, and many years would pass and many take-offs and landings would be made on skis before George Klein became involved in their design.

The very first flight of an airplane piloted by a Canadian was, in fact, made on skis off a frozen lake. The plane was the *Red Wing*, a bi-plane designed and built by Alexander Graham Bell's Aerial Experiment Association.[86] The undercarriage consisted of two runners instead of wheels. This flight, which broke ground not only as the first flight by a Canadian pilot, Casey Baldwin, but also as the first public demonstration of flight, took place on March 12, 1908 in the United States at Lake Keuka, near Hammondsport in New York State's pristine Finger Lakes District. The lake was big and beautiful, but was chosen for the Association's inaugural flight because it was convenient being near the motorcycle factory and machine shops owned by Glenn Curtiss, a key member of Bell's group and a future aviation industry leader.

The first signs of spring were evident with the melting ice and open water in the south end of Lake Keuka. But the flight was a still very much a winter experience, and, as a Canadian, Baldwin felt at ease with the cold air around his make-shift cockpit as the plane took off and landed on the lake's remaining stretch of ice.

The choice and the placement of its ski-like runners involved some experimentation and innovative design. In addition to the main runners, which had a "track of 30 inches", the plane had two small supplementary runners on each side nearer the wing tips to take care of tilting. Initially, the *Red Wing* also had a small runner under the "rudder post" at the tail of the plane, but it was found to be unnecessary and was removed in the Curtiss shops: a decision precipitated, in a sense, by the first aircraft ski experimentation.

It would take another year before the same group of people staged the first airplane flight within Canada's borders. Again the flight was made above a frozen surface: this time it was in even colder winds. The ice was that of Nova Scotia's Lake Bras d'Or and the date was February 23rd, 1909 when John Alexander Douglas McCurdy, the same aviation pioneer who would inspire seven-year-old George Klein on a visit to Hamilton a few years later, piloted the *Silver Dart* into Canadian history books.



The *Red Wing* on runners and the *Silver Dart* with crews on skates
(Canada Aviation Museum – Ottawa)

Designed and built by McCurdy himself, the *Silver Dart* had been flown previously in the U.S. and would make over 200 flights in total.[87] But its first flights in Canada were, like those of the *Red Wing*, clearly winter experiences. They included flights with the special object of practicing landing on ice, and they would form the enduring image of pioneering aviation for Canadians.

The *Silver Dart* did so on wheels, but the ground crew wore skates.

With these achievements just a handful of years after the Wright Brothers made their first flight, Canadians might have been expected to seize the leadership in the winter aspect of early aviation. But it would be close to a decade more before Canada took significant steps to capitalize on its unique relationship with snow, ice, and human flight, and almost two decades would pass before innovators like George Klein helped apply scientific and engineering research techniques to the field.

Baldwin, McCurdy and their Canadian contemporaries tried, but generally failed, in the early years to attract the same high-level support for manned flight in Canada as they and others generated in the U.S. The public was intrigued, but the Canadian government was slow to seize the innovation opportunities.

"The aeroplane is an invention of the devil". Colonel Sam Hughes, Canada's Minister of Militia and Defence, said in response to pleas for government support. "And will never play any part in such a serious business as the defence of a nation".[88]

This perception, of course, changed with the outbreak of the Great War.

World War I presented Canadians in the Royal Flying Corps with many new experiences including winter operations in Russia where they learned that deep snow could make skis essential for aircraft. Back home, WWI saw the first mass production of a Canadian-made aircraft, the Curtiss JN-4 Canuck or "Jenny", a plane that would record many firsts: the first airmail delivery, the first aerial survey, and the first flight across the Canadian Rockies.

It was also the first Canadian-made plane to record a Canadian flight with skis.[89]

Ski equipment was not an uncommon feature on the JN-4 Canucks. Because over a thousand of them were produced as trainers just before the end of the War, there were many left over and available at the War's end to be sold cheaply as surplus equipment to the "barnstormers", who would travel the country putting on demonstrations for a fee in the post-war period. Canadian military pilots and their planes had been discharged from service by a government convinced that the Armistice really meant the end of war. The barnstorming pilots and their war surplus planes found few true landing strips across Canada so floats and skis had an attraction. For many Canadians, their first sight of an aircraft of any kind was a barnstorming Jenny and often one on skis.

Canadian aviation of the early 1920s also witnessed the dawn of bush flying with its watery landings in planes that were essentially flying boats. Dependency on the bush planes grew, and winter magnified the need for supplies. It was natural that other planes would soon don skis to help bring the bush flying era to Canadian winters in the 1920s.

Some thought and engineering skills did go into the use of skis during this period. Manufacturers drew on expertise from other engineering disciplines and other component design knowledge when building and affixing the skis. But steps in aviation technology at this time were "fairly ad hoc, with much of the work being done by craftsmen and artisans".[90] These people were talented and even heroic, but they had little scientific support. "There was somewhat more art than science" in their work.[91]

As commercial aviation came to rely upon all-season service, concern over the weaknesses and the dangers of ski takeoffs and landings grew along with an interest in the affect skis were having on speed and stability.

A Pioneer Bush Pilot goes to University

Fortunately, one of the pioneering pilots of bush flying in Canada was a man who knew a bit of science and suspected that he and his colleagues could benefit from a more systematic and scientific study on the aircraft ski problem.

He was known as "Doc" Oaks.

As Captain Oaks, he had been wounded during World War I, but survived to return to Canada as a decorated hero. Like many of his fellow WWI pilots, he had been bitten by the aviation bug. Unlike some others, Oaks was also interested in higher education and pursued his new interests at university where he combined his love of flying and aeronautics with studies in mining engineering. There at the University of Toronto in the years after WWI, Oaks heard about a young mechanical engineering professor who was attacking aeronautical issues scientifically with unique research facilities that he had built himself. The facilities included a large-scale wind tunnel operating since 1917.

The professor was the future NRC Director and George Klein's future mentor, John Hamilton Parkin.[92]

George Klein was still attending high school in Hamilton at the time Oaks, the university student, first met Parkin and learned about the wind tunnel research at University of Toronto. The research made an impression on Oaks, and aeronautics would comprise some of his special interests at university. But it would be a few years before he would have an opportunity to act upon his instincts and see his ideas pursued at the University of Toronto wind tunnel.

After graduation in the early 1920s, Oaks returned to flying, this time as a mining engineer. He experienced the excitement and challenges of early bush flying including flights on skis first-hand. He was one of the first pilots to join the famed Ontario Provincial Air Service (OPAS) in 1924 and was one of the pilots most responsible for the trail blazing of early mineral exploration in the north. He faced many emergency situations that demanded winter flying in hazardous conditions.

All the time, his knowledge of the emerging science of aviation haunted him. He wondered whether greater technical knowledge could make flight with skis easier or even save lives.

By January 1927, Oaks had risen within the new industry to the influential position of first Managing Director of Western Canada Airways Ltd., destined to be the first major private enterprise in the business (an ancestor of firms that would form CP Air), and he had the responsibility for mail, freight, and passenger services year round in Northern Ontario. He also now had the contacts, position and authority to go back to University of Toronto and induce Parkin and his staff to look into the issues around aircraft skis. Aside from concerns for safety, Oaks would have been most interested in what Parkin and a team, which by 1927 included the mechanically inclined student George Klein, could do to help him in meeting his management responsibility for costs and load limits. Oaks asked specifically if they would conduct wind tunnel experiments on the lift and drag of skis.

Oaks had noted the potential to lose some speed with skis compared to a wheel undercarriage, but it was not clear that the weight of the skis (about "150 pounds" more than wheels at the time) should be considered in setting load capacities.

The research project that resulted was likely the first of its kind anywhere and introduced the young George Klein to studies that would stretch over a quarter century and would help change the map of Canada.

It took a while before Parkin's lab finished its work. But it did provide some answers to questions posed by Oaks. The Parkin-Klein tests suggested that for biplanes, skis would reduce the maximum speed by between 5 to 7.5% over and above that resulting from a wheel undercarriage. The comparable, measured speed reduction for floats was also about 5%.[93]

Aviators had already been looking for ways to mitigate the drag effect of wheels with new devices such as the retractable undercarriages given that wheels alone were found to have a resistance equal to 20% of that of an entire airplane.

Because skis meant an even greater increase in drag and one at least equal to that of the much larger floats, the Parkin and Klein findings were significant and "surprising".[94]

The results were qualified by the scale of the models used in the experiments. At the sizes and speeds prescribed by Parkin's University of

Toronto wind tunnel, small changes would have implications for conclusions projected onto a full-scale aircraft.

Nevertheless, the findings and the testing techniques provided a valid way to make comparisons between various models of skis and to make comparisons between skis, floats, and wheels on comparable models of the planes then in use. The work helped those making design decisions and constituted the formal beginning of the scientific study on aircraft skis in Canada.

Oaks was a unique personality and had a special opportunity to use this knowledge in aircraft ski design. He not only had links to the scientific world, but also had the good fortune to know some unusual Canadian entrepreneurs. The latter group included two brothers named Elliot working in Sioux Lookout, Ontario.

Sioux Lookout, a seemingly remote village hundreds of kilometres from major centres in the Northwestern corner of the province, epitomized the environment and the stimulus that pulled George Klein into the study of aircraft skis. The town had become a busy place as a jumping off point for northern explorers even before the likes of Oaks arrived. Later, in the 1930s, when Klein's own fieldwork took him there, Sioux Lookout's airport had marked a period as the second busiest in North America, after Chicago.[95]

The Elliot boys, Warner and Carmen, came to Sioux Lookout with their families in 1915. After working for a while for the railway, they decided to settle down and go into business for themselves setting up a workshop to build and repair boats and marine engines as well as a host of other wood items of interest to miners, trappers, and others heading into the North country. The Elliots made everything from canoes and paddles to toboggans, snowshoes, and skis.

Even before Doc Oaks came to the brothers for help in the late 1920s, they had had a bit of experience with aircraft having built a ski-like tailskid for one the JN-4 Canucks being flown out of Sioux Lookout.

Around the same time that he approached Parkin and Klein with his ideas, Oaks also started talking with the Elliot brothers about manufacturing his aircraft skis.[96] They accepted the challenge and turned out to be the right men at the right time. Beginning in the late 1920s, the Elliots built a series of unique, Canadian designed skis to help the foreign-built planes adapt to Canadian bush conditions. Their aircraft ski business boomed along with the booming northern development and air transport business over the next two decades.[97]

Their reputation spread, and the Elliots were soon selling their seasoned white ash skis in a wide range of sizes for aviation companies and individuals across Canada and in the

U.S. Before the Elliot brothers retired in the late 1940s, their operation would peak with as many as 25 employees making skis. The brothers would gain special international recognition when Admiral Byrd used their skis on his three aerial expeditions to the Antarctic.[98]

The Elliot Brothers' skis embodied a number of innovations such as having one of the layers laid crossways with others running lengthwise to give added flexibility and thus smoother rides over rough snow and ice. The firm also arranged for the development of a special alloy material to use in lieu of the brittle brass shoeings.

To the extent that the Elliot Brothers were influenced by the ideas and experience of Doc Oaks, they had ties to George Klein's early work as a student under Parkin at the University of Toronto. Doc Oaks and the Elliot enterprise certainly had a stimulating impact on the study of the science of skis.

The results of the wind tunnel collaboration with Oaks were eventually published by Parkin as *Aeronautical Research Paper No. 23, October 1928: Undercarriage Resistance. Bulletin No. 8, School of Engineering Research, University of Toronto.*

Parkin shared the credit with two co-authors: a future OPAS pilot, W.H. Coates, and the young student — G.J. Klein.[99]

Aeronautical Studies of Skis at NRC

It would be a few years before these findings could be amplified by a broader understanding of the forces involved in designing aircraft skis and made useful with prescriptions that would influence ski design on an even wider scale.

During those years, Parkin made his move to Ottawa to take up the challenge of creating and leading the mechanical engineering side of the new National Research Council laboratories. One of the reasons, Parkin's 1929 appointment as Assistant Director in the NRC Division of Physics was quickly followed by the recruitment of George Klein was Parkin's and NRC's anticipation that wind tunnel research and aeronautical studies, such as those involving aircraft skis would be an important role for the Council laboratories.

Under the eye of his aviation-enthusiast, former professor, Klein thus spent much of his first few years at NRC's downtown Ottawa labs designing and building aeronautical facilities such as the "nine-foot" wind tunnel. As expected, the Klein wind tunnel was soon in demand and under pressure to begin research on issues raised by the rapidly growing Canadian aviation industry. In contrast with the devastation wrought by the Great Depression across most of Canada, the country's northern air transportation industry would witness a five-fold increase in business during the 1930s in response to the new opportunities for northern development. Canada would become, by far, the greatest air transport nation in the world, at times outstripping all other countries combined in the amount of cargo moved by air.

Klein and his colleagues were positioned to support the growth of a new domestic manufacturing industry as well as the operators. More and more planes were being constructed in Canada to be closer to the flourishing Canadian market, and eventually, original Canadian aircraft designs emerged. The *Vedette* produced by Vickers in Montreal was the first, but the most successful was the *Norseman* created and constructed in the same city by a transplant from the U.S. named Bob Noorduyn.[100] The *Noorduyn Norseman* was designed with bush flying in mind and with the clear intention of operating on skis as well as wheels and floats. It was tremendously popular and a potent influence on the early expansion of Northern aviation.

In this active atmosphere, Klein's NRC wind tunnel was pressed into service in the early 1930s to the follow up the University of Toronto studies because pilots were still having problems with aircraft skis. The issue was seen as so important that Klein started work even before the wind tunnel was complete.

It would have been with great reluctance and under great pressure that Klein and his colleagues took on the job before key instruments were in place and fully tested in the wind tunnel. But the request came from the Department of National Defence, which was not only one of the greatest supporters of the new NRC aeronautical research team, it was also the government organization with the most influence on aviation at the time.

In any case, the task was a special, early opportunity to show off the facilities.

Klein knew that his NRC wind tunnel on John Street in Ottawa had certain advantages. Unlike its Canadian predecessors, it was large enough to test actual skis, and because ski research was not as interesting to other countries with comparable wind tunnels at the time, Klein had a distinct opportunity to lead the field.

The NRC wind tunnel's size meant that there would be no need to make scale models nor for extensive, subsequent field trials. More importantly, there would be no need to qualify any findings with corrections for scale. They could have a great deal of confidence that what they discovered in Klein's new wind tunnel would be useful and that what they recommended would work.

And they were right.

They tested and measured many of the then commercially available skis. It was challenging work, particularly with an unfinished facility, but it was fun and exciting to test new skills and the available new equipment. The tests involved a number of measurements that had to be precise and correlated. The drag, the lift, the air speed, and other forces as well as specific angles and physical measurements of the skis themselves all needed to be recorded meticulously and then related to each other in a rational and useful way.

Klein soon found that the challenge of inventing a science of aircraft skis, even confined to aerodynamic issues, was much more complex than just measuring the wind resistance of flat strips of wood in various widths and lengths and correlating the multiple relationships. Even that simple exercise would have been daunting in light of the infinite number of possible combinations of width and length.

Yet these measurements alone would tell little if there was no assurance that a particular ski would behave in a consistent and desired way while in flight.

Klein knew that he had to develop skis that combined minimum air resistance with maximum aerodynamic stability.

A central issue was the "pitching moment" or the measured tendency of an aircraft, a wing, or a ski to twist and tip into a nosedive. It is a gauge of the inherent stability of an aeronautical object and, in turn, provides a practical basis for designing trimming gear such as shock cords or other techniques for stabilizing the ski.[101]

If a ski, for example, tended to point nose down at higher speeds, it would increase the drag on the plane and decrease its stability significantly no matter how streamlined and efficient the ski was when held firmly on a flat plane in a laboratory.

Hawker *Audax* on Klein streamlined skis a result of early aerodynamic research (*NRC*).

Klein and his colleague J.J. Green, the scientist who would lead work on the streamlined locomotives, studied many skis including those from the most popular bush planes of the time such as the *Bellanca* and de Havilland *Moth* series. They plotted the behaviour of the various skis with respect to pitching moment and found cogent and clear patterns. They also found great ranges in stability performance between different ski designs suggesting that very stiff trimming or stabilizing cable was needed in some cases and that there was an overall need for basic standards in design for all skis. These observations were magnified when using skis on the higher performance aircraft such as the new Hawker *Audax*, which was, in fact, the plane used in some of their field experiments during this period.[102]

When trimming or stabilizer techniques were proposed and tested, they, in turn, precipitated more tests because each new ski trimming cable system had to also be compared to aircraft wheels to verify air resistance observations.

Tests within tests piled upon tests within tests using facilities not armed with computers or automatic recording devices.

It was painstaking. But Klein, at least, was known as thorough and as someone who liked to look at a problem from all possible perspectives as a matter of course. The style was idiosyncratic, but it was also a feature of a true passion and commitment to the work. It was also essential in the strangely complex study of aircraft ski design.

The complexity of the work was augmented, for example, by the limitations on what one could do to stabilize a ski. Locking the ski in place with a reinforced boot like that used by downhill skiers was not an option because Klein had to also consider what happens when the plane hits the ground.[103]

An aircraft ski would need to not only absorb the shock of take-offs and landings; it would also have to bend with the changing attitude of the plane itself.

Many of the early planes used in Klein's 1930s research, and many still used today, are "tail draggers", planes that act like tripods with two wheels up front and a small wheel under the tail that seems to drag along after landing. Even those planes built to maintain a level posture on the ground still tend to point nose up a bit when taxiing.

The skis and the stabilizing pedestals would, thus, have to have some give to allow for even a small amount of overall tilting while on the ground. Klein's research was thus an intricate balancing act between flexibility and stability, aerodynamics and operations, and wind tunnels and landing strips.

Klein tried a number of ideas, and rejected many. Finally, he and his colleagues developed a technique that worked and worked well. In the lab that is.

They thought that they had found a solution to the combined need for stability, flexibility and aerodynamics when they came up with the idea of attaching little wings to the tail ends of the skis. In their tests, little wings were crafted and placed in a way that counterbalanced the pitching tendency of the front end of the skis while flying. It was a fairly simple task to find the right compensating design, and it meant that the skis could move around a bit while on the ground, but would be forced into a straight flat plane by the wind of flight.

However, even before the field trials were started, they had to concede that the idea was not practical and that they had to abandon it. Perhaps, after conversations with operational crews, aircraft mechanics, and pilots, they realized that little wings, almost little toy airplanes, would not have had much hope for long survival being tossed around in the rugged, day-to-day treatment of bush flying operations.

The hard decision to drop the idea was consistent with Klein's bias for inventions and innovations that were pragmatic as well as elegant. Klein and Green thus decided to sacrifice absolute in-air stability for more durability. But the general concept still marked a step forward in the research.

In the end, they came up with an acceptable alternative, by substituting a modest, but precise alteration to the ends of the skis, a slight turning up, to partly simulate the effect achieved with those little wings. It was a trade-off, but, for the most part, it still produced the desired effect.

It was a humble innovation, but when combined with the data and technical knowledge gained through the extensive measuring and testing of other skis, it allowed Klein and his colleagues to produce a totally new "streamlined stable ski" design that meant a tremendous improvement over all previous ski systems. It was aerodynamically better as well as being much more stable.

The pitching moment was a mere third of normal skis available at the time, and this limited movement opened the door for other designers and innovators to step in with novel new trimming systems, such as a unique internal system which, in turn, helped reduce drag even further.

Together Klein and Green kept on working and eventually produced a ski arrangement that had about one-sixth the drag of normal skis and about a half that of an unfaired wheel (a wheel assembly without a smooth cup cover).[104]

In other words, the usual aircraft ski of the day had about three times the drag of a wheel assembly, but the ski designed by the NRC researchers meant that planes could actually improve performance by donning skis instead of wheels.

A remarkable improvement. It was soon tested by the RCAF on an *Audax* (K3100) at Rockcliffe Air Station. Both the improved performance and the greater control sensitivity predicted by the NRC staff were confirmed.

They had found a way to make skis both safer and more economical to use.

Because NRC was not in the ski manufacturing business, its records do not tell of the full impact of these early findings and innovations or how many skis were produced in Canada and abroad drawing upon this innovation. But it is safe to say that the innovation and technical information influenced ski design throughout the industry.

The techniques were shared freely and widely including with foreign interests in the years that followed, and they were applied by anyone interested in improving aircraft performance. Klein and Green saw their discoveries published as "*The aerodynamic characteristics of aircraft skis and the development of an improved design*" in the *Journal of the Royal Aeronautical Society* in August 1935. The article would be available as a standard reference on the issue.

In any case, the direct Canadian client of their research, the Department of National Defence, was impressed, and the Department had great immediate influence on the world's most dynamic market, not only through its own operations and procurement of planes and skis, but also through its broader role in 1930s Canadian aviation.

Up until 1936, when the Department of Transport was established in Canada, the Department of National Defence controlled all civil air services in the country. Consequently, if in the early 1930s the Department of Defence recommended a design or a finding for general use, which it did on the Klein ski, the design would spread throughout the industry.

A few years later, NRC and George Klein would be asked to refine and build upon these discoveries with more military work within the context of a looming war. In 1939, another generation of wind tunnel experiments were, thus, undertaken to develop skis explicitly for military aircraft including the *Bolingbroke Bomber*, the *Harvard trainer*, and the Hawker *Hurricane*.

The skis that NRC developed for the *Hurricane* would turn out to be the ones with the lowest drag and best pitching characteristics of any seen by any of the Canadian researchers to that time. It was of special interest in light of Canada's very significant role in the manufacture of *Hurricanes* for the war.

The talented, disabled woman, Elizabeth "Elsie" McGill, who had been a student of Parkin at University of Toronto around the same time as Klein, had by 1939 established herself as an innovator and likely the first female aircraft designer in the world. She was given responsibility for production of the Hurricanes in Canada as Chief Aeronautical Engineer at Canadian Car and Foundry Ltd. in Fort William (now Thunder Bay), Ontario.

Her work would make a unique contribution to the war effort.

Of the hundreds of Canadian-built Hurricanes, those that carried skis and other cold weather features developed under McGill's supervision with NRC input would be known as the "winterized" version of the fighter. The standard Hurricanes gained fame during the summer-time Battle of Britain, and after this triumphant performance, winterized Hurricanes were put into action in Russia and other theatres of the war thanks to the innovations made in Canada by young researchers like McGill and Klein.

Klein's role in such improvements to the aerodynamics of aircraft skis during the 1930s was as significant as the advancements were impressive. Yet these were achievements that he shared with others and were largely a function of his access to his unique-within-Canada wind tunnel.

His most important role in the history of aircraft ski design would come from separate work: work that he dominated personally. It would not be the study of wind and the movement of skis through the air. It would come from studying what was on the ground.

Aircraft Skis on Snow

In 1934, even before Klein had wrapped up his involvement in the first aerodynamic studies of skis, the RCAF asked NRC for a parallel investigation into the behaviour of aircraft skis on snow. This work did not involve the wind tunnel and was entirely new for NRC. Klein was given the task and great latitude to pursue his own ideas and intuitions. The study would, therefore, proceed on a separate track, just as the many other projects requiring Klein's skill and support in the 1930s.

Nevertheless, Klein began the task by reviewing all of the literature on snow and ice hoping to find ready-made answers. NRC had a good library and access to the major international journals by this time, yet Klein "found little that could be of help".[105] In later years, he would cite only one mildly relevant study: work undertaken by a graduate student in 1922 at McGill University. This was in reality a study of the "effect of … sleigh runners on snow".[106]

While bush plane owners and the Department of Defence may have been most interested in the implications of efficiency and cost inherent in drag and lift, pilots and the RCAF operational brass wanted to know more about what happens when the ski hits the snow covered ground.

Two intertwined problems were behind the specific RCAF request to NRC. They were also problems that troubled all bush pilots.

First, they sometimes found it impossible to take off because snow conditions prevented smooth sliding. Other times, skis would become frozen or otherwise locked in the snow to the point that they could only be dislodged with a combination of propeller and people power. On a remote lake in Northern Canada, a pilot could find himself and his plane alone without anyone to volunteer as ground crew. Ingenuity was often the only resource. Pilots would, for example, routinely run their planes up on top of logs or other makeshift platforms to prevent "freezing in".

Talent and instinct would compensate on takeoffs and landings, and it is likely that some unexplained tragedies had their roots in the holes that permeated the industry's understanding of ski-snow interactions.

Klein attacked the task with his characteristic diligence.

It is testimony to the degree of his thoroughness that one of his major challenges in fieldwork around Ottawa, one of the world's coldest capital cities, was a lack of sufficient winter. In two separate winters, his work was cut short by an early spring or by a lack of snow. He eventually had to take his work over thousands of kilometres north back to the Elliot Brothers country for field tests.

Again, the challenges were more complex than it might seem at first. It was not merely the process of measuring resistance, load bearing features, and other obvious characteristics of a ski on snow. Each of these measurements had to be correlated with speed, form, and proportions of the ski bottom. Klein also tested the affects of waxing and a variety of ski materials.

That Klein was breaking a new trail was clear in the degree to which he not only needed to invent new methodologies, but also new equipment just to begin his work. This included the design and construction of what he called his "towing dynamometer", a large awkward-looking, triangular metal frame that rode on half-size skis and was dragged along over snow and ice behind a truck or other vehicle. It embodied equipment to measure resistance, attitude, and speed. Klein's instrumentation also allowed him to easily adjust the loads on the skis through ingenious combinations of lead weights that could incrementally increase the pressure by "up to 250 lbs per square foot" on the snow below.[107]

It took most of the winter to build, test, and complete his new research machine, and just as he was about to begin his field work with it, the early Spring of 1935 started eating away at the snow and, more specifically, at the snow conditions of greatest interest to Klein and the aviation industry. After a few trial runs, the research had to be stopped for the season.[108]

Fortunately for Klein's work, the winter of 1935–36 in Ottawa was not short, and by the time, the snow and cold had settled in, Klein and his "towing dynamometer" were ready for action. He, in fact, was better prepared that he had expected to be because the Department of National Defence, a key supporter, had used its influence to secure the loan of a half-track truck from a company in Toronto for Klein's use. The truck, which must have been a rarity as a very early snow vehicle, needed some modifications, but would have been a particularly valuable piece of equipment and a sign of the importance that the Department attached to the Klein ski-snow research.

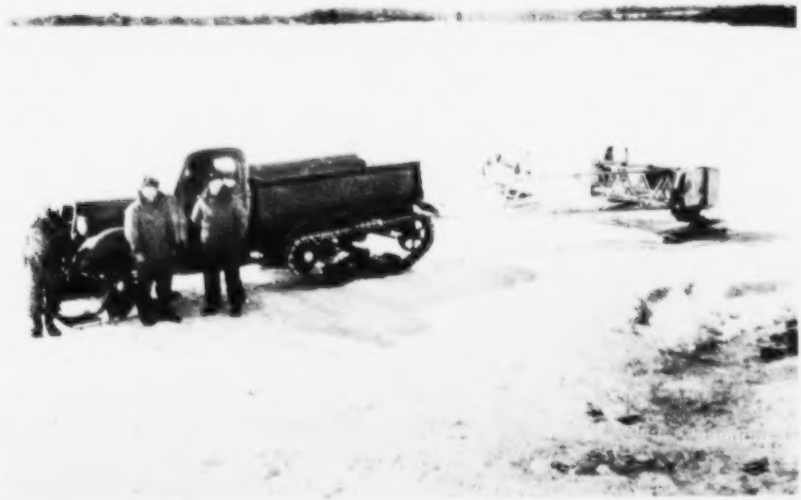
The tests were conducted at the Rockcliffe Air Station east of Ottawa in an area that would within a few years become the base for most of NRC's laboratory research. Testing began in February 1936 and ran for four weeks.

Klein designed, built, and tried out many new skis and coated them with variety of materials – "Beeswax, varnishes, plastics, and metals".[109] As he worked through the data and observed the tests, he began to sense something that was both obvious and yet elusive. The test results seemed to depend more on the existing snow conditions than on the characteristics of the skis being tested and even more than changes in forces, speed, or angle of attack.

Whenever he came up against a roadblock or identified a need for more information, he would "invent" yet another first-of-its-kind instrument, have it made in the NRC shops, and then carry on with his studies. In this spirit, Klein worked over the following summer and snow-less seasons to make more adjustments and additions to his already odd-looking "towing dynamometer". He also started work on new instruments that he hoped would be able to consistently measure the characteristics of the snow as well as the ski performance.

His many new devices included a "photographic microscope" to study snow crystals and the structure of snow. Slowly, he was creating not only a scientific approach to aircraft ski design, but also the tools for others to expand the field. The dozens of models, instruments, and devices he produced for this research were an expression of his customary approach to his job. Indeed, as he created this original ski research equipment, he was doing the same for other fields and other projects throughout the 1930s, most of the time helping others informally or building facilities for many others to use.

In the snow and ski work, however, Klein was clearly amassing something special to empower his own work. He was confident that he had identified the essence of the problem in the snow conditions and now had the tools to solve it. He waited for winter and more fieldwork with anticipation.



Klein's ski dynamometer in late 1930s Ottawa *(NRC)*.

He waited for snow. But it didn't come. The winter of 1937–38 was marked by little snow in Ottawa. Klein ran tests on over 20 of his various ski designs involving a dozen different kinds of materials, but he knew his results and data would be undermined by Ottawa's limited snow conditions. Even though he noted that the plastic-like coating bakelite improved sliding in all his tests, he could not even be certain of this result because of the limited test snow conditions. He had, through a combination of gut feeling and study, come to believe that the snow cover absolutely needed to be part of the research and factored into any meaningful patterns.

Next year, the winter of 1938–39, he took no chances with the snow and moved his fieldwork to Pelican Lake up around Sioux Lookout.[110] The high volume of air traffic in the area combined with the presence of the still operating Elliot ski-manufacturing business made Sioux Lookout an especially good site for Klein to conduct his research, to observe ski takeoffs and landings, to study snow, and to try out new ideas.

Determined to understand more than just the obvious large-scale physical reactions of skis on snow, Klein made further adjustments to his research machinery including the addition of a special test ski with a built-in glass window.[111] He now had a way of witnessing what happened when a ski made contact with the snow and, more importantly, what happened when the ski moved across a snowy surface.

What he saw was water. A thin narrow rim of water was forming around each and every small flat area of contact between the snow and the ski. He was witnessing an effect flowing from action at the molecular level. Not only the movement from solid to liquid, but the surface tension of the interaction of molecules in the liquid. He theorized that this surface tension was a large factor in the resistance of skis on snow. This would explain why the snow conditions such as temperature, water content, and density could affect a ski's performance. These snow conditions could be significant and potentially measurable features and the basis for a rational, science-based understanding of the problems in ski design.

But even this more complex appreciation for the factors influencing frictional drag did not cover all of the issues.

The water around the ski was, of course, the product of melting snow heated by friction, but predicting the effect would be more difficult than correlating it to the speed of the ski. It was also a function of pressure since pressure on the snow would lower the melting point. Klein, thus, saw that another major part of the resistance of skis in snow was a result of the degree to which a ski compacted the snow as it moved through it.

He responded to the challenge by inventing a device that could record the "penetration of a disk to the snow as a function of pressure". He called it his "snow recording penetrometer".

With his snow penetrometer, Klein had a way to measure how resistant various types of snow cover would be to a given pressure on the same object as it came along with his "snow dynamometer". Again, he had to create his own techniques to study the problem and to use the "penetrometer" to relate pressure to penetration.

With this in mind, Klein used the device to not merely record interesting data, but to produce a theory and formula that Klein eventually articulated in stating that *"the part of the ski resistance due to forming a track in the snow is approximately equivalent to climbing a grade having a rise equal to the depth of the ski track in a distance equal to twice the length of the bearing surface of the ski"*.[112] In this respect, aircraft skis were behaving as if they were constantly trying to climb a small hill as high as the track was deep, but twice the length.

A simple formula like this, one that conveys knowledge, discovery, and new understandings, is a powerful tool. It empowers others to invent and design as it transfers ideas and technologies elegantly. As a researcher, Klein could have ended his work at this point with publications and technical reports. But, as a practical, design engineer and builder, he could not resist the challenge and fun of putting his discoveries into practice as well.

He did both. He made the ski and shared the knowledge.

He made a new type of aircraft ski that gave credibility to his theories with improvements to adapt to all snow conditions. Even in the worst conditions for aircraft skis, the sliding resistance of the new Klein ski "was less than half" what had been previously achieved and that nasty tendency of skis to "freeze in" had been reduced to "less than one third of former values".[113]

Klein was ready to share his discoveries and theories with the aviation industry and experts in other countries, and, in fact, presented an interim report at a meeting of the International Commission for Snow and Glaciers in Washington, D.C. in September 1939.

At this point, George Klein was quite possibly the world's leading expert in aircraft ski design. He had not only participated in pioneering work on the stability and aerodynamics of skis, he had almost single-handedly established the scientific basis for designing skis that worked well on snow.

He was now positioned to take the design of aircraft skis to a new level by combining his expertise in aerodynamics with his understandings of skis on snow in a comprehensive work that could be of general use.

But it would many years before he could take that final step and before the full scope of his findings would be shared beyond the immediate interests served by the NRC.

A curtain of secrecy would be drawn over such research, and priorities for Klein's skills would change dramatically. The same week that Klein went to the U.S. capital to present his skis-on-snow research findings, Germany invaded Poland.

War Stalls Klein's Work on Aircraft Skis

At first, it may have seemed that Klein's work on aircraft skis would assume new importance and wider application with the outbreak of a world war.

Indeed, one the very early strategic decisions of World War II was that of assigning Canada a special role in training pilots for the Allied effort under the British Commonwealth Air Training Plan (BCATP). Under the

BCATP, Canada would become what Franklin D. Roosevelt once called the "aerodrome of democracy". Well over one hundred thousand pilots from Australia, New Zealand, Britain, Canada, and other countries would be trained under the program which simultaneously created dozens of small airports and flying clubs across Canada as well as involving large military air bases such as Camps Borden, Trenton, and Rockcliffe.

But, as is often the case with technology development, a separate influence and innovation out of another area changed the context for Klein's aircraft ski work.

Systems for building runways, making them smooth, and clearing snow had been developed in tandem in the 1930s. Consequently, even though the magnitude of aviation activity increased many fold during the first half of the 1940s, the importance of skis seemed to diminish in the framework of more landing strips, airports, and dependable takeoff and landing conditions for wheeled airplanes in winter.

Klein's ingenuity and expertise would be in demand in many, many other wartime projects such as designing projectiles and armaments. His intricate knowledge of mechanical engineering as it related to snow and ice would have an impact in other ways during the war, but his research work on aircraft skis was essentially put on hold.

Aside from pre-war work on the Hawker *Hurricane* and other military aircraft, Klein's understandings of aircraft skis had only one noteworthy impact in the war.[114] Just as in WWI, there was still one theatre of conflict that continued to put a high value on any knowledge that could make aircraft with skis safer, faster, and more maneuverable. In January 1942, Klein was asked to prepare a summary of all of his snow and ski work to that point for this purpose, and all of his studies and recommendations were compiled in a report.[115]

The report had been generated primarily for the Government of Russia. It was challenging time for the Russian airforce not only in the conflict on what Germany considered the Eastern Front, but also in the struggle to protect winter-time convoys of supplies. Klein's pre-war research would thus benefit this unique Allied effort before the War's end.

Klein would not have any other opportunities to revisit his ski research, pull all of the fibers together, nor witness its full impact until after the victory and the start of a new era of aviation, one that would be influenced to an even greater extent by Canadian engineering, design, and ingenuity.

Helping the "World's Greatest Bush Plane" Take-off

The Canadian aviation industry exited World War II emboldened by successes at home and abroad. Overseas, Canadian pilots and Canadian-made aircraft shared in the victories that engendered pride and confidence in Canadians. In Canada, infrastructure, skills, and enthusiasm for aviation had been strengthened dramatically under the BCATP, and an industry that was fledging at the outbreak of the war had definitely sprouted wings and was ready to soar.

Companies such as Canadair, Noordyun, and A.V. Roe were making the transition to commercial business in the jet age with the help of the Government of Canada, the growth of Trans Canada Airlines, and a new interest in innovation and technology in an internationally competitive market.

The National Research Council laboratories and expertise were used increasingly by them all, and these firms, others, and the Canadian military built upon their wartime relationships with NRC research in the development of new aircraft and new strategies.

These included a new, enthusiastic, unrestrained attack on the needs of the bush pilot.

At de Havilland Canada, a variety factors including inspired and visionary leadership came together in a drive to create what would become known as "the World's Greatest Bush Plane".[116] De Havilland assembled a talented design and engineering team that included many Europeans as well as Canadians who had learned new technologies from both Allied and captured German aeronautical research facilities. The people were the core of the company, but a special strength was the firm's intent on listening to bush pilots themselves "especially, the pilots of the Ontario Provincial Air Service" through formal surveys as well as face-to-face discussions.

The strongest message coming out these intense consultations was that, above all else, bush planes needed to take off in short distances, climb quickly at low speeds, and land with similar ease. Small lakes and restricted rivers lined by tall trees were the normal runways of the bush pilots. They cared little about cruising speed or other "niceties" when the alternative forms of transportation were likely to be dogsleds and snowshoes. What they wanted and needed were safe ways to get in and out of tight places.

To respond, de Havilland designed a plane completely dedicated to addressing this issue. From its more powerful Pratt and Whitney *Wasp* engine to its thick-high lift wings and elaborate flap system, the plane spoke to the needs of the bush pilots. It would become the de Havilland *Beaver*: the first in a dynasty of Short Take Off and Landing (STOL) aircraft.

De Havilland had two reasons to pay special attention to the staff of the Ontario Provincial Air Service (OPAS) when designing the *Beaver*.

First, OPAS was by far the premier bush air service in the country and the one with the greatest real world experience dating back to the days of Doc Oaks in the mid-1920s. The service and its counterparts in other provinces grew from the provincial responsibility for natural resources notably forest inventory, survey, fire fighting, and mapping: all activities with enormous application in aviation. The Ontario service with over a million square kilometres of responsibility was quick to acquire flying boats and biplanes in the 1920s.

These planes were ready for retirement and wholesale replacement in the mid-1940s, and this fact produced the second reason for de Havilland's interest in this particular customer for its new product. A sale to OPAS would be the endorsement and the boost the firm would need if it was going to succeed quickly and show a return on the very significant investment made in the *Beaver*'s development: an investment being made by an adventuresome Canadian branch plant of a well-established British enterprise.

OPAS would, therefore, have a great influence on the design of the de Havilland *Beaver* and a claim to part of its success.

The prototype *Beaver*, the CF-FHB, made its first flight, a hugely successful one, on August 16, 1947. This flight and those that followed showed it to be uniquely and consistently capable of clearing "a 50-foot obstacle in 1000 feet" fully loaded. Its performance impressed OPAS, and the Service purchased the first production model of the plane a year later.

But OPAS found that the *Beaver*'s extraordinary results were only consistently achieved when on wheels and floats. When OPAS pilots tried the ski-equipped *Beaver* out on the snow-covered lakes of Northern Ontario in the following winters, they experienced significant "difficulties".[117]

OPAS and de Havilland turned to NRC and George Klein for help.

By the late 1940s, it had become natural for those involved to look to NRC for assistance. De Havilland was well aware of NRC's expertise and facilities because one of the key members of the firm's *Beaver* design team, aerodynamics engineer Dick Hiscocks, had worked at NRC in Klein's Mechanical Engineering Division during the War.[118] Hiscocks would move

Klein skis on the early de Havilland *Beaver* (NRC).

back and forth between industry and the NRC and end his career as a Vice-President of the latter. He would say years later that NRC research data and testing contributed significantly to the *Beaver* development.

De Havilland Canada (DHC) was, in fact, one of those early collaborators that worked with Klein's group on the development of aircraft skis in the 1930s. Up to that time, DHC had been largely dependent upon its British parent for technology and engineering design. But with skis, snow, and ice being particularly "Canadian problems" of little interest to the British, the Canadian branch plant had to find answers on its own and was compelled to seek help in dealing with it. For much of its early years, DHC engineering staff focused on the immediate issues of mass production and competition leaning on NRC for specialized experimental research and invention.

The product of this mid-1930s collaboration with Klein's group was a streamlined ski and landing gear for the *Rapide* aircraft, which de Havilland adapted for use in Canada's north.[119]

Now, in the late 1940s, the issue was serious.

OPAS, the key customer for the firm's new product, the *Beaver*, was having problems in what approached half of its projected operating conditions: snow. The far north of the Province continued to be the focus for the bush flying work, and while the *Beaver* was already recognized as a tremendous STOL success, the plane and the firm's future rested specifically on success in the north.

The problem came at a perfect time for George Klein. When OPAS called upon the NRC for help in improving the *Beaver* skis, Klein was fully armed with years of wind tunnel research, fieldwork, and data that still combined to make him likely the best person in the world of the job despite his war-time hiatus from the field. He knew now that it was not enough just to use the best aerodynamic designs and that there was no such thing as a perfect ski when it came to interactions with ice and snow. He had learned through what were now decades of experience that "optimum performance" could only be achieved with a full and "reliable knowledge of the range of snow conditions for the areas in which the ski will be used".[120]

As it turned out, the lakes that were being used by the OPAS bush pilots, the potential *Beaver* customers, were generally long and narrow, and, presumably, these runway-like lakes were the only ones that pre-STOL aircraft could consistently use. Pilots evidently had what might seem to be a natural preference for long lakes surrounded by dense forests, as this would shelter the water landing strips from the wind.

Klein realized that these specific conditions, when combined with the low temperatures of the north, "greatly retard(s) the settling of the snow". The snow was deep and had many layers. It was not like the wide-open fields that many ski designs had anticipated or even what Klein and his odd-looking "towing dynamometer" had repeatedly traversed ten years earlier. Consequently, although Klein's own skis which he tried out on the OPAS *Beavers* in the winter of 1949 performed better in many respects than other skis, he felt that he still had to do more research and testing to settle upon the best design for the specific OPAS conditions.

Klein set out to produce a new ski that combined knowledge of pedestals and flexibility with increases in both the length and width of the bearing surfaces of the skis. For the *Beaver*, Klein wanted to find a way to spread out the load on the skis. He decided to give the *Beaver* ski a camber, a convex shape, to ensure that the weight would be distributed evenly.

By the winter of 1950, he was ready to test the new design out. At this time, other organizations and potential clients were gaining interest in the *Beaver*, and the next round of tests would, for example, also include work with the Saskatchewan Government Airways.

With the new modifications and more tests, a new *Beaver* ski was produced that proved to be well suited to all relevant Ontario snow conditions.

It was approved by the Department of Transport for use on *Beavers* in all of Canada.[121]

OPAS made an initial purchase of 16 *Beavers*, eventually adding dozens more, and other provincial airways followed suit in the years that followed. Years later aviation historians would call the collaboration on *Beaver* ski design "outstanding" and one of the notable factors in the plane's success. [122]

Later, the *Beaver* would find many uses and many reasons for acclaim including its role as a valued general-purpose aircraft used by the U.S. Army in Korea and Viet Nam. In 1978, the *Beaver* was chosen by the Canadian Engineering Institute as one of the top ten outstanding engineering achievements in Canada during the previous 100 years.

Its was to be widely accepted as the "World's Greatest Bush Plane".

Through the *Beaver* project, Klein had a personally rewarding and satisfying opportunity to finally congeal his accumulated knowledge of aircraft skis in an influential, practical project and to contribute to an important phase of aviation history.

Yet his most potent act during the late 1940s and early 1950s may not have taken place in the engineering shops, the wind tunnel, or the northern bush, it may have come sitting before a typewriter.

In 1950, his thoughts were coalesced, and drawing upon years of aircraft ski research, he drafted reports and scientific papers that gave a comprehensive picture of the field and were presented in many conferences and countries. A comprehensive review, the work covered his "Theory of Ski Resistance", the aerodynamics of skis, and previously unpublished findings from the *Beaver* field research in a way that exuded a set of general principles that would guide aircraft ski design and engineering throughout the world.[123] It was an impressive legacy and covered a quarter of a century of research, which was significant at the time given that the entire history of powered flight was less than half a century old. It was likely "a sort of Bible" of aircraft ski design for many engineers during this time.[124]

Nevertheless, these reports only hint at the essence of the unique knowledge Klein had gained through his years of aircraft ski research. He would make a greater, more influential contribution in a field of study that reaches far beyond the snowfields touched by aircraft skis: snow itself. But even this work would be delayed for a time by the pressures of war.

"... differing from Klein's design only in details included to facilitate mass production ..."[125]

4. THE DEVIL'S MACHINE

There are many mornings in a soldier's life when he opens his eyes, looks at the damp walls of his tent or stares at a faintly lit sky wishing in one way or another that he could float above the ground ahead. His wish is not always an expression of fatigue or lethargy although there is no overstating the leg-dragging labour of long slippery marches through mud, brush and swamps. His dream can, when the terrain ahead is an unexplored minefield, acres of natural hazards, or a covering of thick undergrowth, be a longing for safety and survival.

When he faces a path of heavy wet snow leading to a battlefield, a soldier may imagine himself floating simply because of a desire to get the job done. One military unit famed for such drive and a capacity to "get the job done" under all conditions was the First Special Service Force (FSSF), an elite band of both Canadian and American soldiers which would, by the end of World War II, come to be known as "the Devil's Brigade".[126]

George Klein, a man who was born too late for active service in the First World War and would be spared the worst of WWII, helped to found the Devil's Brigade with his science and helped to give this special fighting unit and many other soldiers the potential to float over the ground.

Credited with many Allied successes on the road to Rome, breakthroughs in the south of France, and strategic victories between the two, the men of the FSSF were hailed as a gleaming triumph throughout the War. They were later celebrated in palaces, in presidential citations, in almost all war histories, and in Hollywood.[127]

They were proud, highly trained, and regarded as exceptionally heroic men even in circumstances where bravery was commonplace. They never gave ground in some of the worst fighting of the war and could be described as the world's best at their specific tasks and in their time. The Force "was unique. It was the sole parachute-ski-command-type unit of the World War II Allied Armies"[128] trained to be "expert demolitionists ...(who)...underwent a special type of hand-to-hand combat (training) taught by a former Inspector of the Shanghai Police".[129]

The special multinational make-up of the unit and many of the innovations it embodied were also features of a unique, new machine designed to help its members, in essence, "float above the ground": the *Weasel*. A particularly effective all-terrain assault vehicle and one that was called the world's "first successful military snow vehicle",[130] the *Weasel* was eventually mass-produced and used by many other military units and civilian adventurers in important battles and severe conditions around the world. But it was designed and first made specifically for the Devil's Brigade.[131]

It was designed in part by George Klein.

Klein's Odd, but Brilliant new "Friend"

The ideas and forces that launched development of the *Weasel*, the creation of the FSSF, and Klein's work on military vehicle design first came together in early 1942 in the mind of the eccentric British inventor and military advisor Geoffrey Pyke.[132] George Klein would come to know Pyke well and to consider him as an odd, yet brilliant, possibly "too brilliant", colleague.[133]

Few would disagree with Klein's assessment of Pyke, an unusual man with a wild imagination and a relentless ability to talk and write about his ideas.[134] His personality and confidence were fuelled in part by a string of early life successes, which included widely celebrated exploits as a journalist behind enemy lines during WWI. Under the sponsorship of the British paper the *Daily Chronicle*, Pyke went to Berlin to send back reports from the heart of the Kaiser's Germany. He was, perhaps predictably, soon captured, but was spared from a firing squad and, instead, sent to a prison camp.

Pyke escaped through a bold daylight break and returned to Britain to great publicity. He came to believe that his escape was due to his innate ability to think and dream in a "scientific" manner.[135] After the world returned to peace, Pyke made money in the 1920s Stock Market, and later spent his modest wealth to promote his scientific ideas and new approaches to education. This combination of profile and innovation brought him to the attention of political figures and eventually into a position with Lord Louis Mountbatten's Combined Operations bureau. Here Pyke had a special venue to develop and push big ideas in the early years of the Second World War and to eventually change research priorities in Canada.

The first months of 1942 were a particularly bad time for the Allies.

The War was tilting toward the Axis powers with Japan's dominance in the Pacific and with Germany's fresh attack on Russia. The latter conflict precipitated inquiries about Klein's aircraft ski research, and within a few months, it would present much greater demands on his lab in Ottawa.

There was, during this period, considerable pressure on the Allied nations to open another "Front", but Britain and its allies were far from being ready to launch Operation Overlord or any other full-scale entries into Axis-held Europe.

An alternative to such an all out assault on Europe lay in the possibility of a series of strategic raids to sabotage enemy installations and draw resources away from other theatres of war. The coast of France had drawbacks, and Canadians would illustrate this point with their blood on the beaches of Dieppe later in the year.

Pyke saw Northern Norway as an attractive venue for such raids. Neither a scientist nor a military man, he still had an unusual influence on British military planning because of his access to Mountbatten for whom he would write hundreds of pages on the variety of geographic and strategic reasons for raids on Norway as well as other ideas.[136] He had so thoroughly considered his plan that even his abrasive personality and unusual, often unclean appearance, which ran from his dirty spats up to his scraggly goatee, could not completely blind the military planners to the merits of the scheme.

In any case, British military leaders were already aware that Hitler was using Norway as an air and sea base to attack conveys on the way to Russia. Furthermore, the then Nazi-controlled heavy water plant in Norway was of growing interest to the atomic research programs on both sides in the war and a priority target for Allied sabotage.

Pyke believed that a major Norwegian raid could eventually draw thousands of German troops away from other theatres of war.[137] He would gain support in Britain at the highest levels. In fact, his idea would become a pet project shared by Churchill as well as Mountbatten. Pyke's whole plan rested on two pillars: the rapid development of an entirely new type of snow vehicle and the creation of the specially trained fighting unit that would use it. Both arms of the project were to touch George Klein's work and life in profound ways.

Pyke's unfettered mind considered all aspects of the raid from how the troops might hide in glaciers to the possibility of disguising the snow vehicles as mobile "Latrines for (German) Colonels Only " as a way of removing the need for a guard and thus extra weight in the vehicles.[138]

In any scenario, Pyke's envisioned snow vehicle would need to meet particularly demanding requirements. Light enough to be carried in aircraft in quantity and possibly dropped by gliders, the machines would still need to be durable, powerful, and able to climb through all types of snow.[139]

Pressed to the limit by the immediate crises of war, British industry did not have the capacity to produce the snow vehicles in the needed quantities, and as a consequence, the British scheme was soon conveyed across the Atlantic to U.S. military leaders, who would, in turn, engage U.S. industry. The Americans also decided to call in Canada's new National Research Council on the project, possibly because of some awareness in scientific circles of the skis-on-snow work which had been presented in Washington just before the war.

Even before the U.S. officials came calling on Ottawa, they, the Brits, had cited Canada as a desirable partner in the Norway raid project simply on the assumption that the large Northern ally would have some special experience with ice and snow.

And Canada did have something special — in George Klein.

Klein and many others in Canada were ready to accept the possibility of military snowmobiles thanks largely to the pioneering inventions and work of Armand Bombardier and his staff in Valcourt, Quebec. In fact, early in the War, Bombardier, the firm later synonymous with snowmobiles, produced over 100 military units using Ford V8 engines and based on the half-track civilian design (suspended half on tracks and half on skis much like today's personal snowmobiles) which the firm had developed, produced, and sold prior to the War.[140] General Motors also produced a half-track vehicle using the Bombardier design around this time.

But each had their drawbacks. Bombardier's inaugural military product was excellent in good snow conditions, but suffered from excessive ski wear and poor manoeuvrability in wet snow and mud. GM's first effort was too heavy for its "borrowed" Bombardier-style design and only a few were ever manufactured.[141] Both companies, Bombardier and GM Canada, would adapt and later produce much more successful military vehicles by the war's end.

Regardless, in 1942, Pyke and the British high command wanted something different.

George Klein was prepared for the challenge. Klein's 1930s ski research had not only led him to develop special experimental equipment for fieldwork,[142] but had also given him unique insights into the mechanical properties of snow and ice and their interactions with other materials. He read, and he published, and as a consequence, when Canada was asked for input on the issues around the highly secret snow vehicle project, it was able to impress the U.S. and British teams with Klein's extensive unique material. Klein had, of course, just completed his studies on ice and snow on the eve of the War.[143]

Klein's early reports and methodical work would have been especially interesting and perhaps a pleasant surprise to Pyke who had complained in both Britain and the U.S. that the challenges around his snow vehicle concept were not being attacked from a scientific perspective and, specifically, without attention to the physical nature of snow.[144]

Before the summer of 1942, a small international committee of technical experts was struck to attack the development of the new snow machine on an urgent basis. Because of his apparent expertise, Klein was appointed to this small committee; it would become the central team overseeing the project. Klein's role on this Committee would expose him to one of the top military secrets of the war and lead him into an active role in the design and technical development of the vehicle which would come to be known as the *Weasel*.

At this point, the proposed military snow vehicle was not called the *Weasel*. It was being developed under the codename "Plough". Short for "snow plough", "Plough" also became code for the entire Norwegian invasion plan, thus emphasizing how much the scheme was tied to the as yet non-existent snow machine.[145]

Britain's initial request for assistance on "Plough" involved formal proposals and high-level missions. Mountbatten himself came to North America in 1942 and participated personally in these entreaties. In no small part because of his advisor Pyke's odd demeanour, it took some initial arm twisting in Washington and eventually the involvement of President Roosevelt and a then, little known general named Eisenhower before the U.S. military agreed to oversee the design and engage U.S. industry in the development and production of "Plough".

The idea and Pyke received a slightly warmer reception in Canada.

Not being a soldier, Pyke had trouble working with the military brass, and he even struggled with his ostensible colleagues from the world of science in the U.S. and Britain. He did, however, find a fellow enthusiast in George Klein.

Klein saw Pyke as a person with great ideas but merely lacking the skills to apply them.[146] He doubted Pyke's claims to being a "technical" or scientific advisor to Mountbatten, but recognized that his new British "friend" was powerful and that the snow machine project was a genuine priority.[147]

It was May 1942 when Pyke and his British colleagues made the rounds in Washington. Within a month, they were in Ottawa, and it was during this period, on June 12, 1942, that Klein formally began his work on the Plough vehicle design Committee. He met with Pyke soon after, and whether it is fair to say the two men "hit it off" immediately, they certainly found things to talk about and shared some enthusiasm for the project.

Pyke and Klein would stay up all night talking about the potential to build a super snow machine upon their first encounter. It was four in the morning when Klein noticed the time and decided to head home from the Chateau Laurier, some distance from the Klein's Ottawa residence.[148] The cabs had stopped running. Klein had to walk home arriving just before dawn with the challenging task of explaining to his wife that he had been working on a secret project at the hotel all night.[149]

It is easy to imagine the excitement that might have flowed from the confluence of Pyke's passionate dream and Klein's special understanding of ice and snow science. Klein's technical knowledge and success with aircraft skis would certainly have amplified Pyke's belief that something unique was truly possible.

Klein would give the project all the help he could, starting with an open and liberal sharing of all of his relevant studies to date and later with his active involvement in design, field tests, and even production. Pyke was vocally appreciative.[150]

The Brigade prepares to use the *Weasel*

Meanwhile, the human side of the plan was being brought together with the same drive and enthusiasm. A young U.S. officer, Colonel Robert T. Frederick, was appointed to recruit, train, and lead the FSSF. Even though "Plough"[151] was dependent upon the pending development of an entirely new type of military vehicle, the formation of the requisite special fighting unit could not wait. The urgency of the war allowed for no other option.

Weasel during trials in mud and snow for use by the future *"Devil's Brigade"*
(NRC Archives – US Army Photo)

Consequently, as Klein and others were struggling with the engineering issues, the Force itself was being assembled at full speed.

The choice of Frederick to lead the FSSF would turn out to be one of the most inspired military appointments of the War. Years later after Frederick's battlefield success brought promotions, Churchill would call him the greatest fighting general of all time. Despite a lack of combat experience and an initial lack of enthusiasm for the project, Frederick proved to be an extremely effective leader with the right combination of bravery and wisdom for the task. As with any such success, many would claim credit for the appointment. Although it is likely that Mountbatten had a large say in it, it appears that Canadian government officials, possibly people at NRC, also helped by supporting it based on their positive experience with Frederick during his initial review and consultations with NRC officials in Ottawa on the Plough Project proposal.[152]

Frederick had been the analyst assigned to assess the British Norway plan for the U.S. military. He recommended against it in a detailed brief that was not accepted by his superiors, but ironically was seen as thorough enough to make him the most knowledgeable, available officer to lead the new force.

Frederick's steps included establishing a training camp for the FSSF in Helena, Montana in July of 1942 at Ft. William Henry Harrison. A remote, isolated, and cold place, it was the perfect venue to prepare for Norwegian-style winter conditions and training on the new snow machine. In addition to the expectation that they would adapt to the snow and cold more easily, the Canadians in the Force were also considered elite and highly trained while their American colleagues have been described in many accounts as less professional and even criminals and misfits.[153] In fact, Canada had already established its own 1st Canadian Special Service Battalion and other similar units, and started commando-style training even before merging it with the American unit to create the combined FSSF.[154]

In any case, all of them, Americans and Canadians, had to undergo tough screening to be accepted, and it is likely that the weeding out of the severe training program and the trials this entailed meant that, in the end, all of them could be fairly labelled elite and special. The refined and polished collaboration was certainly more powerful and effective than the sum of its parts.

At first, it was an awkward, multi-national collaboration that mirrored the blend of government, military, industry, and scientific hands that Klein was facing in the *Weasel* development. But it worked.

The FSSF recruits trained to be parachute troops, but also ones who were expert in a wide variety of weapons and explosives. They had to withstand brutal winter conditions, know how to ski, be skilled in rock climbing, and, by the end of their training, capable of operating and maintaining the *Weasel*, as the Plough snow machine was already being called by the time it would arrive in Helena.

Frederick would have had his hands full over that first year of 1942–1943 without having to worry about the technical and production problems that Klein's engineering colleagues were enduring with the *Weasel*. But the Colonel was not allowed the luxury of ignoring them. Even though Pyke got along well with Klein, the British inventor's ongoing personality conflicts with American designers made it clear that Colonel Frederick would have to be involved in the engineering design work on the *Weasel* as well as supervising the preparation of the Force.

As Klein and the other international planners had prescribed, the *Weasel* would need to meet exceptional performance standards. The raid would only succeed if the troops had a way to attack with speed and escape quickly. The *Weasel* was an essential and focal element of all military planning, and its development was thus followed closely by Colonel Frederick. In fact, he and his officers would eventually have more input than Pyke on the project, and as others sought to work around Pyke or to sideline him altogether, Frederick would find himself caught in between.

It was thus that Klein came to know Frederick, who found himself in Ottawa along with Mountbatten and Pyke for the meetings in 1942, not only to maintain Canadian military support for Operation Plough and a commitment of troops, but also to recognize the value of Canada's National Research Council with its talented engineer Klein in the *Weasel* development. Klein and his colleagues on the international team were told by Frederick and others that they would have to have the prototype *Weasels* ready for use by the time the FSSF trainees entered that first winter of 1942–1943, and this put them under a lot of pressure.[155]

Here in Canada, Frederick would find some relief. Not from Pyke with whom, the new FSSF commander would have the pleasure of sharing his Ottawa hotel room, but rather some relief from his concerns over the military and technical support he would receive for the project.[156]

Frederick would describe his meetings in Ottawa as "highly satisfactory" largely because of the enduring bond and understanding he had established with the Canadians.[157] At these meetings, the Canadian brass not only committed to supplying more highly trained and elite soldiers, but also offered up test sites as wells as the resources of the NRC for the development of the snow vehicle.[158]

From the point that the engineering plans were clarified, the development of the snow vehicle coloured much of the planning and development of the Force. For many months, Frederick and his staff would spend a great deal of time working with Klein and other engineers dealing with the seemingly endless issues involved in bringing the vehicle to production in the U.S.[159]

In this way, Klein and the others involved in engineering and the vehicle design work truly became partners in the launch and creation of the Devil's Brigade even though the *Weasel* would not be used as originally intended.

A Creative Carmaker is tagged as the manufacturer

Once the U.S. military brass in Washington accepted in the inevitability of "Project Plough" and the need for a large number of snow machines to implement it, it turned almost immediately to the Studebaker Corporation to line up production. Studebaker, which was engaged in the project very early on, even before the summer of 1942,[160] was based in South Bend, Indiana, a town Klein would visit often over the next year.

Studebaker, which was by then a well-regarded, century-old American enterprise, had not only established itself as an innovative carmaker prior to the War, but also had a track record in supplying military vehicles. The world's leading maker of horse-drawn wagons in the late 19th Century, Studebaker had even benefited from the demands of the U.S. Civil War in the early years of the business, and well before the attack on Pearl Harbour, Studebaker had launched a line of military trucks to supply the Soviet army in fending off the invading German army. Their trucks, which worked well in snow, became so familiar in the Soviet Union that the word "Studebaker" was adopted as Russian slang for truck.[161]

It would be wrong to suggest that War was seen as good for business at Studebaker. The outbreak of War brought a collapse of foreign markets for automobiles, and the U.S. entry into the conflict put restrictions on supplies and materials that made it extremely difficult to continue existing product lines. Military business was a matter of company survival.

Studebaker had resources to offer the war effort: production experience, trained people, management teams, and networks, and despite some bitterness over the government move to control systems of production, the firm's management was anxious to put Studebaker in the path of the U.S. Government military contracts. In addition to the trucks, the company also subcontracted to build aircraft engines and other products during the early part of the War.

While the U.S. military could have considered other firms for the Plough/Weasel contract, Studebaker was eager for work and, possibly, in the right place at the right time.

The Plough/Weasel project, with its military interests and Klein's multinational oversight committee, was unusual and a potential headache for the carmaker.

But any trepidation that Studebaker might have had over accepting the challenge would have been mollified by the U.S.'s new "cost-plus" system of military contracting. The system was instituted to protect military suppliers from the wild fluctuations in costs that wartime conditions could bring and to make investments in new plant and equipment attractive. Studebaker was a pioneer and champion of this contracting system. [162]

It guaranteed the company a profit and insulated it from the risks that the development, testing, and modifications that a project such as the new snow vehicle would demand. It is also possible that this system injected a desensitization to costs and efficiency that would later contribute to Studebaker's need to withdraw from the vehicle manufacturing business and to its eventual disappearance as a corporate entity.

Nevertheless, before this final phase of the company's history, the company would experience a special challenge and test as the firm tagged to be the maker of the usual snow machine dreamed up by Pyke and guided by foreign experts such as Klein.

The snow machine was something different for the company, but not something beyond its engineering and manufacturing skills. Because of the obvious pressures of the War and the projected schedule for Project Plough, production had to begin immediately and even though some development and testing was anticipated, this meant that the vehicle was, by necessity, to be based upon known technologies, established approaches, and largely available parts and materials. The firm's existing Champion engines were used, for example.[163]

These constraints were at odds with the vision Geoffrey Pyke had described to Klein: one of a super machine, uniquely capable and innovative to the point of providing the Force that would use it with a strategic advantage. In fact, Pyke felt that this unique technical capability was essential to the success of the mission. He was looking for the best as opposed to the best currently possible. Pyke would, for example, advocate an approach based on a review of first principles through studies on the fundamental mechanical properties of snow and its interaction with vehicle transportation systems.[164]

In the end, the Studebaker engineers would be largely spared the adventure of working directly with Geoffrey Pyke. In the early days of Pyke's time in North America, he was tied up in selling the concept to the authorities in Washington and securing commitments from those in charge in both Canada and the U.S. By the time, the production of prototype snow machines was underway, FSSF C.O. Frederick and others had devised strategies to manage Pyke's direct involvement in the work on the snow machine as well as the planning for the troops. Consequently, a buffer had been created between him and the Studebaker engineering managers.

Nevertheless, the Studebaker staff felt the general parameters of size, performance, and utility as dictated by the invisible hand of Pyke's envisioned Norway raid. With these boundaries, George Klein and the others on the design team quickly determined that the vehicle should not carry heavy armaments, should be built to carry a small number of men, and be all-tracked as opposed to the half-track and half-skis design being used on the then available Bombardier machines.

Even without Geoffrey Pyke's interest and eye on their shoulder, the Studebaker team would have, no doubt, still been under considerable pressure simply because of the heavily implied importance of the task. Not only were they to have hundreds of the vehicles built within months for use in training of the Force in Montana, they had an extra layer of supervision breathing down their necks in the form of military officers, who were visible on the shop floor and in the engineering labs.[165] The military presence, which included FSSF C.O. Colonel Frederick, was likely an impatient one, more concerned about costs than company management would have been and less interested in technical issues than results.

They were also being watched over by the multinational design committee that included George Klein. But they likely welcomed Klein's involvement. He spoke their language, supported most of their ideas, and, as all would see, he had unique, useful knowledge to bring to the table.

Klein's Contributions and Vision for the *Weasel*

George Klein's senior-level role in Project Plough, his special input to the technical design of the *Weasel*, and his contacts with people like Pyke and

Frederick largely flowed from his unique expertise in the mechanics of ice and snow. The knowledge and data garnered from his aircraft-ski studies gave him an entry card to the project and its part in history.

Klein's special insights in this field are credited for critical contributions to the design of the *Weasel*'s tracking system, and his most credible claim to influence on the *Weasel* rests on these ideas.

But his other observations and design proposals for the *Weasel* are equally impressive.

When he was asked in early 1942 to prepare an urgent report on relevant technologies, the directive was not restricted to his special expertise, but was instead a broad request for information on "all possible forms of vehicles suitable for transportation on deep soft snow" with particular emphasis on climbing ability and speed. Klein was effectively asked to give advice on what type of vehicle should be developed for a wintertime raid.

Like the Studebaker engineers, Klein was given some basic guidelines, likely defined by Pyke's very clear vision for the raid as translated by the British military planners. Klein was told, for example, that the vehicle had "to be capable of transport by glider", but also had to meet specific requirements as to load and range.

Klein was, thus, to consider the whole vehicle and not merely the subcomponents related to his own studies. As instructed, he quickly pulled together a report that concluded that work should focus on an all-track vehicle designed to minimize the unit pressure between the track and the snow.[166]

In addition to the issues of weight and all-track design, considerations covered by Klein's report included the need to strive for near uniform track load distribution, the precise location of the vehicle's centre of gravity, the shape of the belly and its clearance, and the benefits of a clean and accessible suspension system. Klein also described the optimal track tread form, length to breadth ratio of the track, and size and spacing of the wheels that would drive the track.

Many of these suggestions were echoed by Studebaker engineers and other sources and had, in fact, already been recognized even before Klein's report had been submitted. But it is testimony to Klein's instinctive "design and engineering smarts" that he would reach many of the same conclusions as experts in the field of vehicle design and manufacture, an area which had only been of modest prior interest to Klein.[167]

Whether Klein's report was seen as largely stating the obvious or a useful endorsement of the conclusions of others, it provided enough evidence that the author was a wise and practical person to conclude that Klein should be the requisite Canadian on the international design team. Much as Colonel Frederick's memo criticizing the Plough concept tagged the young U.S. officer as the most knowledgeable candidate to lead the Force, Klein's name on a thorough technical report had made him the obvious choice for the assignment.

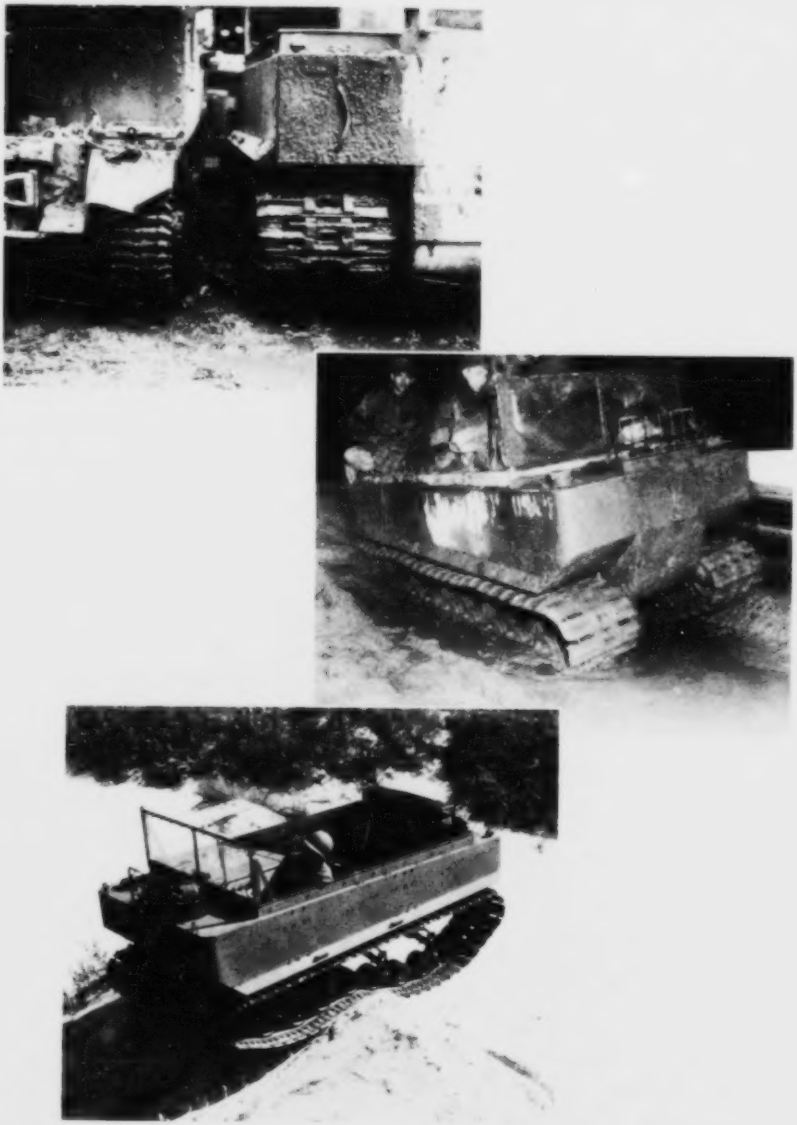
One unique feature of the initial Klein report was its stress on the challenge of wet snow. Klein pointed out that wet snow when compressed, as it would be by a vehicle, would form solid ice on any tracks, wheels or sprockets. The problem could even immobilize the vehicle and require frequent cleaning if not precipitating a complete breakdown. The only solution Klein could see was the use of all-rubber track, rubber tired wheels and rubber-faced sprockets or sprockets shaped to be self-clearing.[168] Klein knew from experience that the flexibility of the rubber would cause such ice to bend and break off.

The Goodrich Rubber Company, a Studebaker supplier, had produced certain types of rubber tracking systems before, and it was, in fact, approached about the possibility of providing a light all-rubber track for the new snow vehicle.[169] But the Goodrich engineers did not feel that their product could be made as light as the Canadian had suggested and still fulfill strength requirements set for the *Weasel*.

A prototype *Weasel* was, thus, developed and manufactured using all metal tracks.

Klein remained convinced of the merits of his design and continued to pursue the idea in Ottawa independent of his work for the main prototype vehicle in the U.S. Fortunately for Klein, he worked at an organization and in a section that would not only tolerate such independent initiative, but also support it with a unique environment of facilities and collaboration. George Klein would comment often that he was lucky to be in an organization that had expertise in so many fields. He would speak gratefully of how he could find an expert, perhaps even the world expert, within walking distance if he ever encountered problems in other fields such as chemistry, electrical engineering, or biology.

He credited this easy access to varied expertise as one of the forces that made him so successful in his projects. Others would, at the same time, credit easy access to Klein's design and engineering talents for their successes.



Weasel tracking system with conventional vehicle – and Weasel in action in WWII Europe *(NRC Archives – US Army Photo)*.

It was this environment that allowed Klein to proceed to develop a light all-rubber track of his own, and, eventually, to produce a half-scale model of the length of the track needed for a *Weasel* at NRC. At the time, NRC had its own Rubber Laboratory in Ottawa, and Klein was able to convince the lab to help him out.[170] The NRC design, which was a creature of laboratory scientists, was not perfect. It presented a number of difficulties for those who would have to apply it in actual industrial production. But it was successful enough to reopen the issue and convince the U.S. industrial engineers that the all-rubber track was still a possibility.

It was also enough, in fact, to change the minds at Goodrich. Its engineers proceeded to collaborate with Klein and the other NRC staff to work and rework the track design several times until all of the requirements could be met in a way that was also practical from a production point of view.

It was good that they took another crack at it.

While Klein was working under his own authority on the rubber tracking system, work on the first experimental Weasels had been going ahead at Studebaker, and they were duly sent to the Columbia Ice Fields in Alberta for trials on snow.[171]

The weather cooperated to create the wet snow conditions needed to show up the design weaknesses predicted by Klein. Tracks and sprockets iced up to the point of making it impossible to operate the vehicle and casting the entire project into doubt. This gave Klein an opening to make his suggestions anew to a receptive audience.

The sprockets were redesigned to be self-cleaning as Klein had originally recommended, but because of the schedule defined by the planned Norwegian raid, time did not allow for a complete retooling and manufacture of all rubber tracks for the vehicles. Still, the merits of Klein's observations were clear so the next best alternative was adopted. The track plates were coated with a thick layer of rubber.

Weasels fitted with the new sprockets and the rubber-coated track were delivered for training of the Devil's Brigade base in Montana before the end of the 1942–43 winter, and they reportedly "gave no further trouble in wet snow conditions".[172]

As a result, the Studebaker Corporation was asked to continue the development of the *Weasel* and to produce more as a production model identified as the M-29. With more time and larger orders, Studebaker's supplier produced all-rubber tracks for the final versions of the *Weasel "differ-*

ing from Klein's design only in details included to facilitate mass production ...".[173] In fact, the load distribution on the track and the location of the centre of gravity of the final production version of the vehicle were altered and followed Klein's design recommendations more closely than what was the case in the original prototype Weasels.[174]

George Klein was a very modest, polite and physically small man, who had never seen a blood-covered battlefield and who could not claim great expertise in vehicle design. Yet on the *Weasel* Project, he could hold his own and push his ideas in the midst of powerful personalities like Pyke and Frederick and experts in U.S. industry.

Klein's strength in such circumstances came from his focus on the technical issues and a genuine, deep desire to be truly helpful.

Although the *Weasel* was the product of the ingenuity and vision of many people from Pyke to the engineers at Studebaker, it was very much as George Klein had instinctively predicted when first challenged by the product, and it was clearly much better for his involvement in its design. Its subsequent success is testimony to his intuitive genius, persistence, and easy ability to work with others.

An Exceptional Machine and a Model Multinational Partnership

The *Weasel* worked.[175] The First Special Service Force came together as a coherent and primed fighting unit especially skilled for the mid-winter Norway raid, known in its final stages as Project Jupiter.

Yet neither the Force nor the *Weasel* would ever be used for their originally intended purpose. The Norway raids were cancelled in early 1943, and for a brief period, the value and the future of both sides of the project were in doubt.

The *Weasel* was neither as light nor as powerful as Geoffrey Pyke's wild imagination had originally prescribed, and his intricate plans depended upon each piece fulfilling its role completely. At the same time, there were persistent doubts among the military brass over the innovative training and mixed bag of men that the FSSF comprised.

However, in the end, it is likely that both the FSSF and their machine were too good. When the plans for raids into Norway were cancelled, it was ultimately a decision strongly influenced by the withdrawal of Norwegian support.[176] The Norwegian Resistance may have initially welcomed the proposed influx of Allied troops into their homeland. But it is easy to understand how they might have reconsidered their position as time went on and the plans became crystal clear.

The objective of the exercise was not the immediate liberation of Norway, but rather the destruction of the country's industrial infrastructure and disruptions that would draw many thousands more Nazi troops into the country. Neither of these effects would be good news for the citizens of Norway. It is possible that the successful trials and production of the *Weasel* and the increasing readiness of the FSSF magnified the images of a prolonged guerrilla-style war, starving innocents, and tightened Nazi occupation.

While military historians might ponder what impact the FSSF equipped with their new vehicle might have had on history had the men and machine been used for their intended purpose, both the Force and the *Weasel* benefited from the cancellation of the special winter raids.

The cancellation meant the two, which had been locked together as part of a coherent plan, were now freed of each other. The FSSF was free to attack other missions not dependent on the snow vehicle,[177] and the *Weasel* was now being considered in a different light. Rather than just a snow machine, it was recognized as an exceptional all-purpose military transport vehicle, useful in a variety of conditions.

The vehicle's unique design produced pressure on the ground that was less than a quarter that of a fully-equipped soldier, and this feature combined with its smooth underside, low centre of gravity, and tracking system to make it an extremely effective mode of transport in mud, swamp, and underbrush.

Studebaker went into mass production with the design influenced by George Klein. By the end of WWII, the Studebaker had produced 15, 000 of the vehicles, and for years, it would see variations of its product used in many conflicts, many environments, and many tasks.

The M-29 *Weasel* and its amphibious brother M-29C saw lots of action during World War II.[178] From the landings in Normandy and Anzio to the swamps of South East Asia and the island-hopping War in the Pacific, it was not merely useful, but the crucial advantage in mud and water that prevented other vehicles from advancing. Even years after the War, authoritative U.S. military sources (U.S. Marine Corps Gazette 1949) would call the *Weasel "one of the most versatile weapons thus far introduced to war"*.[179]

Weasels remained popular for decades and were used in the Arctic and Antarctic by adventurers and troops on military exercises.[180]

It stands as the first successful military snow vehicle and thus a milestone in transportation.

The Studebaker Corporation emerged from the war and its military contracts as a stronger company, at least for a while. To the extent that the *Weasel* influenced the fortunes of the Studebaker business, the project also produced indirect benefits for Canadian vehicle manufacturing and Canadian industry.

In fact, Studebaker's final car assembly operations were in Canada. Several years after it had shut down its historic home base in South Bend, Indiana in the early 1960s, Studebaker was still producing cars for the world market in Hamilton, Ontario: the city of heavy industry where George Klein was born. The *Weasel* remains a small, but unique feature of the history of the Studebaker company and the car industry.

Yet George Klein and the others who worked on the development of the *Weasel* and Project Plough may have had their most enduring impact through their modest contribution to the Devil's Brigade. Their technical innovation helped make the creation of this specially trained, multi-national force an attractive and seemingly viable enterprise at a critical phase.

Klein knew that the Force that would be using the *Weasel* was something special as the project drew him into secret meetings on troop movements, military planning, passwords, and clandestine trips to the U.S. He traveled by train to avoid attention and often could not even tell his wife of his whereabouts.[181] It would, in fact, be years before he could discuss any details of the project.

The FSSF did become a powerful weapon for the Allies. As commando raiders, the Force earned its intimidating nickname in Southern Italy where its members became the first troops to break out of Anzio, enter Rome, and move on to establish beachheads that allowed the Allies to move into the South of France. They took ground that seemed impossible to others and became a terror to their enemies.

Although the Force was broken up into Canadian and U.S. national units in 1944, its offspring survived in different forms and, not surprisingly, produced lines leading to special operations units such as the U.S. Green Berets and Canada's airborne troops.

But it was as a collaboration between countries that it stood apart, and it provided a model for those, such as Nobel Peace Prize winner and future

Canadian Prime Minister Lester B. Pearson, who would, years later, propose such United Nations multi-national forces.

In the end, the *Weasel*, the Devil's Brigade, and the impact they had were significant, impressive, but unexpected.

They were products of all out efforts toward a grand dream that harnessed the practical talents of people like Frederick and Klein and may, in the end, merely stand as simple testimony to what can happen when humans think big and work hard together.

We have achieved the "Liberation of Neutrons
in the Nuclear Explosion of Uranium"[182]
Halban, Kowarksi, Joliot-Currie, Perrin
Paris, March 8, 1939

5. CANADA'S FIRST NUCLEAR REACTOR

In the early part of 1940, a "nuclear explosion" took place near the downtown area of Canada's capital city.[183] It was inside a building that is not far from 24 Sussex Drive, the address of what is now the Prime Minister's official residence. The "explosion" was also well within sight of the Parliament Buildings.

Few people would today use that phrase — "nuclear explosion" — to describe Ottawa's 1940 nuclear events, which were little more than a modest laboratory project only detectable with novel measuring equipment. But "explosion" was the term some leading experts were still uttering at the time as they groped to convey the image of their new technique: nuclear fission — even when it was "sub-critical". They knew that fission was an event that blew the nucleus of an atom apart sending its neutrons flying off like microscopic shrapnel and releasing energy, sometimes barely enough to measure in a laboratory, but tremendous on a relative scale.

With today's perspective on top of more than a half century dotted by dramatic and awesome "atomic age" developments, the small-scale, limited experiment of early 1940's Ottawa seems more akin to a tiny spark than an explosion. But this spark produced persistent embers that would, a few years later, help draw Canada, and with it George Klein, into what stands as one of the most gripping, intrigue-laden, and momentous research projects of the century: the quest to unlock the atom and to control nuclear energy.

The tiny "spark" from this early Canadian nuclear research project would thus help light the way to the development of a multi-billion dollar Canadian industry and to Canada's status as the first country other than the United States to build a functioning nuclear reactor.

Klein was fated to become the design engineer for that first Canadian reactor and, through this work, to contribute directly to the development of much bigger projects including a second reactor which would for a time be the world's most powerful.[184]

Klein was not a nuclear physicist, not involved in the earlier experiments in Ottawa, and still only vaguely aware of the issues involved in subatomic research when the reactor assignment was finally dropped on his desk in late 1944. To see Canada's nuclear story through his eyes is, therefore, to come closer to the experience of Canadians not involved in the science. It is to see the story from the perspective of a young nation still finding its identity between Europe and America, still dependent upon its natural resources, and still seeking recognition as a scientifically advanced country.

The combination of these qualities positioned both Klein and Canada to assume a surprising and significant role in the nuclear age and all that it has wrought.

Canada's entry into the field is, of course, a merger of stories involving politics and war as well as science and geography. Each begins and evolves independently, but in many ways, they all came together around George Klein's work and role.

Natural Resources and Northern Exploration meet Nuclear Physics

Despite the varied forces at play, it is perhaps, even 60 years later in the midst of a technology-driven society that has many reasons to shed the self image of "hewers of wood and drawers of water", likely that most Canadians would still see the natural resources and northern wilderness link as the easiest aspect of their country's nuclear history to grasp and accept. It begins with an ancient geological formation in an ice-age location.

Today the existence of a substantial Canadian uranium mining industry is well known, as is its association with the nuclear industry.

Before 1940, uranium deposits were being mined in Canada, but it would be hyperbole to say that there was a uranium mining industry. Uranium was merely an unwanted by-product of the production of radium, which was the main object of the Eldorado refinery in Port Hope, Ontario. Radium was being extracted from pitchblende ore shipped from a mine on the shores of Great Bear Lake along the Arctic Circle. The deposit had been discovered just 10 years earlier by Canadian prospector Gilbert Labine.

Labine, an Ottawa Valley native who went west with his brother for adventure in the 1920s, had only limited success prospecting for Canadian gold under the Eldorado name, but it was enough to finance further exploration. Working with pioneering bush pilots including one of the legends, Punch Dickins, Labine held onto his hope and used his last dollars to search for silver in the far north. He failed to make a major silver strike, but his unanticipated discovery of pitchblende would have a greater influence on Canadian history than any precious metal he might have uncovered.[185]

At the time of his discovery, the only substantial radium mining operation in the world was in Africa's Belgian Congo. The African mines held a virtual world monopoly in products that constituted one of the few options for cancer therapy at the time and comprised key materials for some of the most compelling areas of scientific research. The market and prices defined by this monopoly gave Labine the motivation and drive to not only lead the development of his remote, Arctic mine, but also the design and construction of the unique Port Hope refinery.

Labine and his Eldorado refinery, therefore, were most interested in extracting radium for the lucrative world markets, and while uranium oxide was also being produced incidentally in large quantities, its principal destination was storage and disposal.

By the time uranium became a matter of great scientific and military interest during World War II, Labine's operations (even though his mine would, at times, be temporarily shut down) had given Canada an international reputation and new strategic importance. Eldorado was eventually taken over by the government to protect the supply and assure Canada's U.S. and British Allies of its security within the growing nuclear program.

George Klein, of course, had Labine, Punch Dickens, and their kind at the front of his mind for much of his first decade at the National Research Council as he worked on bush plane designs, aircraft skis, and wind tunnels.

Research in Klein's facilities helped those carrying very Canadian loads such as canoes and camping equipment on aircraft and helped Canada deal, by the mid-1930s, with its world-leading airfreight business.[186]

The development and exploitation of Labine's mine was a well-known example of the impact of Canadian aviation and aeronautical research around NRC in the 1930s. The mine was very dependent upon air access, and NRC researchers helped Labine establish the value of his deposit as well as designing barges in Klein's marine towing tank that would service the mine.

In projects like these, Klein demonstrated a practical bent and easy association with the needs and challenges facing explorers and pioneers of the rugged edges of a still young country. He was an engineer and technical person whose laboratories often had the ambiance of fieldwork.

Yet, by the time World War II began, Klein had also learned to walk comfortably among his country's senior science leaders and most brilliant researchers. One that would eventually be counted in both groups was Dr. George Craig Laurence, the man who created those barely detectable "nuclear explosions" in NRC's laboratories in Ottawa in 1940.

George Laurence achieves fission on a shoestring

Klein knew Laurence well, and liked him although he was a different man. They were both central figures in the close-knit core cluster of originals in the NRC labs. Laurence's was one of the six new faces that came to the NRC's Division of Physics only a year after Klein had arrived as the Division's first employee in 1929.

Although officially regarded as the "professional" researcher at NRC during that first year, Klein had been hired at a time when NRC managers were not looking for experienced scientists.[187] They had very modest space for research in their old buildings on John Street, and the full-scale laboratory building down Sussex Drive was still three years from completion.

Mindful that the immediate tasks involved building labs as much as using them, the NRC managers who hired Klein were seeking bright, promising young graduates, who had demonstrated a willingness to work hard and take on junior technical tasks. They were less interested in basic research at the time.[188]

Klein, the mechanically inclined engineer who had shown a flair for the very practical side of research, was happy in this environment.[189]

His friend Laurence did not always feel the same.

The Great Depression strangled hopes of an ambitious research program and large staff at NRC's new laboratories, and those who were at NRC would be challenged by a greater emphasis on work tied to industrial benefits and desperately needed economic growth. This practical side of the Division swelled until it broke off taking Klein with it into the separate Division of Mechanical Engineering under Parkin in 1936, and then, the stress on short-term work aimed at immediate results would be magnified at NRC by the advent of war in 1939. The short-term work would, in fact, colour much of the research at NRC for most of the 1930s and 1940s.

Despite the obvious seriousness of the times and the immediate pressures, Klein, once again, enjoyed himself and his environment, and he would later call this period one of "serious fun" in the labs.

Laurence, however, felt isolated and a bit frustrated. Born in 1905, he was young too, but had already done significant science before arriving at NRC.[190] A Charlottetown native, Laurence was a bright undergraduate who showed enough promise as a student to earn a scholarship that took him to Cambridge's renowned Cavendish laboratories where he would gain exceptional research experience while earning his doctorate.

He thought he had the best of all worlds when he returned to Canada and a post at the new national laboratories in Ottawa in 1930. At NRC, Laurence would find, as did George Klein and others, many opportunities to apply his insights and knowledge in industrial projects. Laurence, a rare master of the barely understood phenomenon of radioactivity, was made head of the X-Ray and radiology section. There, he would have a satisfying impact on cancer therapy and on industrial inspection systems based upon this field throughout the 1930s.

But after seeing the world's best at work at Cambridge, he found it difficult to be out of touch with basic research. He tried to keep up by reading scientific publications, and through them, he learned of the experiments with uranium and the discovery of fission, and, like his contemporaries in other countries, he followed the developments and discoveries flowing from leading European labs with great excitement, but he felt alone at times.

This feeling was magnified when a curtain of secrecy was pulled down over fission research after war broke out in 1939. By this time, however, Laurence, sitting in his laboratory in Ottawa, had already recognized the potential.

Laurence, his curiosity, his interest in basic research, and his knowledge were functions of scientific developments dating back a half century and symbolic of Canada's steps toward scientific maturity.

In fact, for Canada, this part of the nuclear story began when the future baron and Nobel Laureate, Ernest Rutherford, arrived at McGill University in Montreal in 1898 to take over the lead in what, thanks to the generosity of education lover and Canadian philanthropist William MacDonald, could be described as the best physics lab of its kind in the world at the time.

In this Montreal lab, from 1898 to 1907, Rutherford began experiments on atomic phenomena that greatly expanded upon the then recent discovery of a subatomic particle, the electron.[191] Rutherford produced in Montreal some of the first experimental evidence of radioactive decay. Later at Cambridge, his research and teaching would constitute the foundation for nuclear research in many countries. One of his students and research assistants at Cambridge was George Laurence.[192]

Notwithstanding this impressive-for-the-times pedigree, his appreciation for basic science and the new discoveries in physics would not, ironically, have been enough to cause Laurence to act on his ideas were not for the knowledge he gained from the more practical side of NRC. Through this, he knew that Canada had a unique opportunity because of the excess uranium at the Eldorado operation in Port Hope. He asked Gilbert Labine's entreprise for a supply.

Labine owed Laurence a favour because it was Laurence's lab at NRC that had helped prove the superior quality of Labine's radium deposit and thus boosted its competitiveness with the established mine in the Belgian Congo. Even at this point, uranium had yet to be recognized as valuable and strategic.

Laurence was encouraged to pursue his ideas with the access to uranium, but he also understood that a large quantity of natural uranium would not be sufficient to succeed in producing nuclear reactions with a sustained release of energy. This would only be achieved if the neutrons released during fission could cause another generation of fissions followed by another and another, each releasing energy and spurting out more fission-causing neutrons.

Because the fission of a single uranium nucleus releases between two and three neutrons, the potential for increasing numbers exists. But research had already shown by the late 1930s that many of these neutrons either escape from the scene or are captured by other materials. Self-sustaining nuclear fission does not happen naturally, and we do not see nuclear explosions in nature or when a uranium deposit is simply exposed to neutron spewing materials. This is because of the very low concentration of the specific fissile isotope, Uranium 235, which constitutes only one part in 140 of natural uranium.

Clearly, one way to increase the chance of a sustained nuclear reaction would, therefore, be to increase the density of U-235 in the material being bombarded with neutrons. But the process of purifying or enriching uranium had not been worked out in 1940.

Laurence could see that he would not have any way of overcoming this enormous technical hurdle, so he turned his mind to the other way to increase the number of fissions from a given experiment. This would be to find a way

Klein's colleague and Canadian nuclear science pioneer George Laurence during his early days at NRC *(NRC Archives)*.

to slow down the released neutrons because they are most effective as fission instruments when moving at a specific speed. This meant placing his uranium among layers of a moderating material.

Materials containing very light atoms such as hydrogen were considered prime candidates because they were more likely to slow down, but not stop and capture the fleeing uranium neutrons. Ordinary water was tried in some laboratories without success. Of the possible moderating materials, carbon had a special attraction to Laurence because it was widely available and cheap.

Cheap was an important quality to Laurence who was contemplating this experiment as something over and above his day job: something he would undertake, because of his passion for pure science, on weekends and evenings.

In the spring of 1940, Laurence set out to build an experimental pile using natural uranium and material used in graphite as his carbon moderator there on the third floor of the NRC's palatial, neo-classical stone building that still fits nicely into the Prime Minister's neighbourhood of embassies and historic homes.[193] Before the year was out, Laurence would become the first person in the world to record fission in a large graphite-moderated uranium pile. This experimental pile, literally a lattice of piled bags of uranium inside a graphite filled wooden bin, was similar to what would be recognized later by Enrico Fermi's team of U.S. researchers as the best, short-term way of producing the sought-after "first self-sustaining (nuclear) chain reaction". Fermi and company achieved this more celebrated and significant milestone in Chicago in December 1942.[194]

Laurence fell short of this more ambitious goal simply because he lacked the budget and resources for materials of the requisite purity.

Laurence's pile would be known as a "sub-critical" experiment.

In any case, Laurence did achieve and record, with his own arrangement of Geiger counters, nuclear fission, and, as the first such experiment with a graphite-uranium pile, something that would catch the attention of U.S. and British science leaders including Dr. John Cockcroft, the future Nobel Laureate, knight, and leader of nuclear research, as he and others passed through Ottawa in the following months.[195]

The Laurence experiments, a function of Canadian knowledge as well as natural resources, were to give Canada an essential element of credibility that would have major implications for Canada, NRC, and George Klein.

George Klein might have been able to help Laurence with the construction of his experimental pile. But in 1940, Klein, like the rest of Canada, was not aware of what was ahead and certainly not aware of the less-than-microscopic Laurence "explosions" on what was then called Sussex Street.

As a university student and later at NRC, Klein had more than a passing interest in the revolutionary theories of Einstein and his contemporaries which permeated the physics world in the early part of the 20th century. He also had the same opportunity as Laurence to follow the international speculations and breakthroughs around nuclear fission. But these things seemed remote, and the only awareness Klein may have had around Laurence's first work in 1940 would have been to ask himself why the National Research Council had put an extra lock on a certain Sussex Drive laboratory door. Aside from Laurence, only his Director and one or two assistants would ever stick their heads inside that room.

Klein did not notice his colleague being particularly tense or nervous during this period. Aside from the overall ambience of war and the pressures it created for all of NRC, Laurence did not sense any serious drama, as he knew that his experiment did not involve quantities that could cause a real explosion.

More likely, Klein might have noticed and cursed the curious soot-like trails of spilt graphite material that sprinkled hallway floors and smeared across the soles of NRC shoes. Several tons of uranium and graphite were moved into the building for the experiments. Klein would be told that the NRC was merely using some of the excess space that the Depression-era budgets have left empty to store materials for other laboratories.

But Laurence's reputation was growing, and four years later, when George Klein was asked to join the effort to build the first "self-sustaining" nuclear reactor in Canada, he would recognize that the project and its implications for his own life and career as being connected to George Laurence's work.

Heavy Water Heroes Come to Canada

Despite having only vague knowledge of Laurence's early research, Klein was, by 1944, well aware of one specific development in nuclear science—the importance and value of heavy water — even before he was told the detailed requirements of the heavy-water reactor he would be building. In fact, he had some special knowledge that even the senior levels of NRC would not have had because of his work on the *Weasel* and with the Devil's Brigade.

While graphite or carbon materials had an appeal to people like Laurence as cheap and widely available moderators, heavy water (water with molecules containing the heavy hydrogen isotope deuterium) was recognized as being better. But it was tremendously expensive and hard to make too.

Before the war, the only facility capable of the large-scale production of heavy water was a Norsk Hydro electric plant in Rjukan, Norway. Norwegian scientists had convinced the plant to use its equipment and expertise in other electrochemical products to add heavy water production as a minor sideline business. At the time, it was little more than an oddity of interest to scientific laboratories, but this changed in 1939.

Researchers at the Collège de France in Paris were the first to firmly conclude that heavy water would be the best moderator for nuclear fission research and act on it. The team was led by Frédéric Joliot-Curie, husband and colleague of Madame Curie's

Dr. Lew Kowarski, one of the "heavy-water heroes" of WWII and Klein's scientific supervisor on the ZEEP project *(Atomic Energy Canada Ltd. (AECL) photo).*

daughter, along with two men who would play important roles in Canadian history and George Klein's career, Hans von Halban and Lew Kowarski.[196]

Building upon recent discoveries in Germany and elsewhere that established the feasibility and implications of uranium fission, the French team started its work with heavy water and could easily have produced the world's first self-sustaining chain reaction, had the War not disrupted their research program.

They wanted, naturally, to secure as much heavy water was possible for their research, and when German military interest in heavy water became evident, the French government helped them obtain all of the existing Norwegian supply. In the spring of 1940, the entire 185 kg Norwegian stock of heavy water, likely the world's only large supply of heavy water, was poured into cans and carried out of Norway by a French agent who, suspecting that he was followed by his German counterparts, booked himself on a flight to Amsterdam, but took a plane to Scotland instead. German planes forced the first plane to land in Hamburg, and the heavy water, which rode on the second, landed in Scotland and eventually made it back across the English Channel to Paris.

The Nazis invaded Norway and later France. The cans of heavy water had not yet finished their wartime adventures. After a brief stay hidden in a prison cell in the French countryside, they and some of the French scientists fled to England in the summer of 1940 just ahead of a boat that was sunk by a German mine and in the midst of an attack by Luftwaffe bombers.

Joliot-Curie, who would later join the Resistance, stayed behind to tell the invaders that the world's supply of heavy water had been lost with the sunken vessel. Halban and Klein's future friend Kowarski were on the boat that did get away and would form the core the British-French heavy water team in the Cavendish laboratories in Cambridge. The German occupiers started up production again at the plant in Norway.[197]

George Klein had, of course, been told all this in June 1942 at the secret meetings on the *Weasel* project, and it was these issues that energized his discussions at the Chateau Laurier Hotel with Geoffrey Pyke.[198]

The Canada-U.S. Devil's Brigade plan to raid Norway was motivated in large part by the existence of the heavy water plant and the desire to undermine the German nuclear research program. Klein was focused on the mechanics of ice and snow,[199] as they related to the *Weasel* project, and only paused briefly to think to himself about the larger implications of the mission.[200]

Although the *Weasel* was never used to raid the heavy water plant in Norway, it was seen as a technical success because of the machine's wider use, and Klein's involvement in the project added to his reputation for usefulness and to his knowledge of what was at stake in this war.

Klein could have heard about heavy water around NRC, as well, because some of his colleagues there had been called to work with the Consolidated Mining and Smelting Company (later Cominco) in Trail, British Columbia earlier in the War. The Trail operation became the first North American heavy water production facility with NRC help.[201]

Halban and other players in the heavy water saga would settle in Canada along with those original Norwegian cans, after they made one last harrowing trip across the U-boat infested North Atlantic. When Klein was being briefed on his new assignment, he would be told at first that he was merely helping to construct another scientific research facility.

But when he heard the phrase "heavy water moderator", he knew "it had something to do with "the bomb" and the race to end a war that had yet to be won. [202]

Threads are Pulled Together at Canada's NRC

Because of his general awareness of efforts to build an atomic bomb and his prior knowledge of wartime interest in nuclear research, Klein would not be surprised in late 1944 to be told that the design of a Canadian nuclear reactor would be highly classified and secret.

However, he would be surprised at the degree to which steps were being taken to protect the program and the degree to which the U.S. military was involved.

It was not the first top-secret project he had worked on nor was it even the first in which the American military had a major say. The *Weasel* was just one of his many military research projects that involved high level security and clearance from partners in other Allied countries. Klein had never had any security problems before. In fact, he had been assigned his own password, "I forgot to bring my skates", to facilitate his movements across the Canada-U.S. border with secret documents.[203] His work was often cited in code in communications from the NRC, and he was given assignments of personal interest to absentee President and Commander of Canadian Forces in Europe, General Andrew McNaughton.[204]

But the nuclear program was different.

The U.S. military leaders, epitomized by General Leslie Groves, the senior army officer with ultimate control over the Manhattan Project, were very concerned about their northern neighbour and its involvement in nuclear research.[205]

These concerns had been mitigated somewhat by the time Klein entered the scene, but they were still intense enough to force a two-month delay before Klein could be cleared and deemed to be what his Director Parkin would later term "pure enough to receive details of what he was to do".[206] Klein's experience was a direct expression of the degree of influence the U.S. military had over the Canadian project at the time. In fact, years after the War, Parkin would complain about U.S. soldiers on site providing security and checking credentials at the NRC nuclear laboratories on Canadian soil. Klein's boss would eventually refuse to participate in related work for this reason.[207]

It was not like this in 1942, the year following the bombing of Pearl Harbour. For that year, U.S. nuclear researchers, government officials, and military personnel appeared generally enthusiastic about the prospects of collaboration with British and French scientists. The U.S. was building up its nuclear research program rapidly, but the heavy water team at Cambridge and other groups from Britain seemed to have an edge in many areas and, at the very least, some unique intellectual resources to bring to the table.

When the German bombing of Britain and the growth of North American scientific effort combined to suggest that the Cambridge team might be moved across the Atlantic, there was even some initial discussion of a U.S. home,[208] such as Chicago.

However, Canada moved quickly to provide an alternative that was more acceptable to all parties. NRC's Acting President C.J. Mackenzie, who did not personally believe that a bomb would be built in time to influence World War II,[209] saw a unique opportunity for Canada to step onto the ground floor of a field that could have tremendous industrial benefits and to do so in a way that would forever change the scientific and technological infrastructure and culture in Canada.[210]

Mackenzie facilitated an arrangement that saw Canada contributing considerable resources to support the Cambridge team's placement in

Canada as the core of a major new NRC administered research laboratory. Montreal was chosen over Ottawa, NRC's primary home, as the site of this new lab for several reasons, possibly in deference to the French element of the team, but more likely for secrecy and the low profile. An international team would be less noticeable in a larger, more cosmopolitan centre. The availability of new space at the University of Montreal would later add to the benefits of this city.

A Canadian home for the Cambridge team seemed viable in 1942 because of the spirit of cooperation that U.S. partners had shown.

But by early 1943 when the NRC's Montreal lab started operations, then headed by Halban, one of the French heavy water adventurers, this spirit of cooperation had evaporated and a period of poor morale, lack of direction, and low productivity ensued. It is possible that Fermi's breakthrough in December 1942 not only stimulated massive military interest and the race to build the bomb, but also convinced those calling the shots in the growing U.S. program that they did not need the fledgling Canadian project with all the security risks that its multi-national membership offered.[211]

The U.S. Manhattan Project was, by then, taking effective control of the Allied uranium and heavy water supplies. Without U.S. cooperation, the Anglo-Canadian NRC nuclear program was essentially stalled. This did not change until a secret collaboration agreement between Churchill and Roosevelt at the mid-1943 Quebec Conference reopened discussions culminating in a change in the leadership at the NRC Montreal lab and U.S. endorsement of a specific task for it.[212] The task that would embrace Klein.

In early 1944, Dr. John Cockcroft, the British scientist who had toured George Laurence's lab at the outset of war, was selected to head the Canadian lab. Cockcroft had established impressive nuclear physics credentials with experiments a decade earlier and was now experienced in high-pressure research management. He had the combination of credibility and talent needed to turn the Canadian project around.

With strong support not only from senior Canadians including Mackenzie and NRC's powerful Cabinet Minister C.D. Howe, but also the U.S.'s General Groves and the British who reluctantly gave over his services, Cockcroft was positioned to act.[213] He and the Canadian team had a mandate to move ahead with the construction of a large-scale heavy water reactor.

Although not directly tied to the race to build a bomb, those involved knew that their Canadian project would produce knowledge of use to the

U.S. military program. The Canadian program would, in fact, eventually lead to the production of bomb grade materials that would be sold to the U.S. and Britain over the next decade to finance much of the development of the Canada's nuclear interests.[214]

By mid-1944, Cockcroft and NRC managers had chosen the specific location for the needed nuclear research complex, one that had the requisite access to water supplies and remoteness at Chalk River, about 200 km north of Ottawa. Cockcroft also had enough power and respect to suggest a radical change of the well-defined plans for the project.

This Chalk River laboratory complex was being built to support the construction of a large-scale heavy-water nuclear reactor. The project involved much more than the simple construction of a new scientific facility. It was a multi-million dollar enterprise, enormous for its time and complicated by many factors beginning with the atmosphere of war. The reactor was named the NRX (National Research Experimental) research reactor, and this remained the main objective of the Canadian program.

Sir John Conceives a Baby Reactor

Early in the planning for the project, Cockcroft determined that the best way to approach it would involve the construction of a much smaller test reactor that could, hopefully, be brought into service more quickly and safely and could be used to try out theories and design options for the more costly and complicated NRX. Work had already started on the NRX so questions were asked about the need for what seemed like an interim step.

It was a deviation from the initial plan, and some felt that this baby reactor might divert resources and attention from the main project. But Cockcroft managed to sell the idea to his colleagues, and, more importantly, to the Americans who now controlled the major Allied supply of heavy water even though it was being manufactured in Trail, BC by this time. He must of have been convincing as General Groves, whose Manhattan Project was still more than a year away from bearing fruit, approved the requisite increase in heavy water to the Canada for the second, smaller reactor, and the project was launched.[215]

Cockcroft assigned overall responsibility for the construction of the small reactor to Lew Kowarski, a member of the original French heavy water team and one of those who had escaped from France with most of the

George Laurence and the powerful figures behind Klein's ZEEP project. NRC President C.J. Mackenzie, Cabinet Minister C.D. Howe, and Dr. John Cockcroft (left to right) *(AECL)*.

world supply of the substance four years earlier. There was some appeal to giving Kowarski, a strong and bright personality, a quasi-autonomous project.[216] He had stayed at Cambridge and refused to join the Canadian-based effort until Cockcroft had replaced Halban, that other central figure in the original French heavy-water team. Kowarski had personal difficulties with Halban who apparently continued to treat his colleague as a junior long after their scientific credentials had come into balance.

Kowarski, the proud father to be, chose the name for the baby reactor. He called it ZEEP for Zero Energy Experimental Pile. Although ZEEP would have, at times, a greater capacity, the intention was to operate in the realm of a zero energy output, which was sufficient for a number of important physics applications. These would allow scientists to test geometries, materials, and other core reactor components without the complications that heating introduces into the study of chain reactions. However, in the mid-1940s, the zero energy reactor also had the attraction of simplicity and safety.

Kowarski, a scientist whose mind had for many years been consumed by the basic physics of the project, had also been trained as an engineer and was not incapable of overseeing the engineering design and production of the ZEEP project. But it was still a complex undertaking involving barely understood phenomena. He would need a lot of help.

The Project is "Assigned to Klein"

NRC President C.J. Mackenzie suggested using the resources of his Division of Mechanical Engineering, and on September 8, 1944, Cockcroft met with the Division Director, J.H. Parkin to discuss the idea for the first time.[217] Parkin barely knew of NRC's involvement in the nuclear research having only learned of the Montreal lab that year, but he knew who the right person would be to lead the engineering design and construction side of the ZEEP project.

"The project was assigned to Klein".[218]

At first, Klein was not impressed with this new opportunity to contribute to the war effort. His lab was in very high demand, and dozens of his projects had the air of extreme importance. This one would not instantly appear to be any more important.

Many of the jobs on his plate, in fact, seemed more urgent and real than the construction of a device based upon new atomic theories and very long term science. Notwithstanding vague discussion of a link to "the bomb", the objective of the ZEEP was initially hard to visualize, particularly with scant information.

He considered it to be merely something else that had been "loaded" on his group, which already had many masters to serve.[219] In their numerous war-time projects, the Klein engineering team, a group of gadget makers, problem solvers, and material scavengers, usually assumed the role of junior partner in an enterprise led by another part of the Division of Mechanical Engineering, another part of NRC, or even another organization.

Klein's relationships with Kowarski, the senior scientist and overall head of the ZEEP project, and with the larger NRX-focused group in Montreal was, therefore, not unusual. Klein was accustomed to responding to the priorities of others, to adapting to the vision of another, and to working with those whose interests came from a different direction.

Kowarski, a Russian by birth who had traveled far before and after his adhesion to the drama-soaked French heavy water team, had risked his life on several occasions to pursue his research. He believed that his work and the race to develop nuclear fission in advance of Germany would save the world. Klein did not initially share this experience and basis for passion.

Klein would thus depend entirely upon Kowarski and his scientific second-in-command, the New Zealander Charles Watson-Munro, for their understanding of nuclear physics and the basic science of the ZEEP project. He would not question their intent or their basic requirements.

Yet the project and ZEEP would, in the end, not only bear Klein's stamp and influence, but would be very much a "Klein" creation.

While he did not make pretense to scientific understandings he did not have, Klein had clear views on how to make a novel device work and how to get the job done. On this, he would have many arguments with senior and much more experienced figures in the Montreal group, and he would prevail.[220]

He needed considerable confidence within his own responsibilities, as he was not only surrounded by Nobel caliber scientists, but engineers of the first rank as well. The Montreal lab's Engineering Section comprised senior engineers from the giant British firm Imperial Chemical Industries (ICI) who could already claim several years of nuclear engineering experience. Klein also worked in the shadow of an impressive team of engineers from the Canadian firm Defence Industries Limited (DIL) and its subcontractor Fraser Brace who were charged with the overall management and construction of the novel and massive Chalk River complex. Each had specialized expertise including backgrounds in large-scale, sophisticated energy developments that demanded respect.

Still, Klein working on a project, some 50 times smaller in scale than NRX alone, managed to persist and focus on his own task in his own way.

Klein's voice was one calling for simplicity and straightforward approaches. There was so much to this project that was new and extraordinary[221] that he would argue in favour of simple and proven design choices whenever the option presented itself.[222]

This was typically Klein's style. But he had special reason to keep things simple and reliable. While Klein and his colleague Don Nazzer faced many unknowns in designing ZEEP, they were certain that failure was not an option. The accepted view at the time was that "if any part of the reactor failed – it would be necessary to abandon the site and go away for a century or two!"[223]

It was wartime, and supplies were scarce, but Klein knew that he had to use aluminum of specific purity, only a certain kind of stainless steel, very thin-walled containers, and complete barriers to humidity. The frightening implications to any mistakes made work tense at times, but he remained focused.

ZEEP was Cockcroft's decision, and Kowarski's vision. But Klein's design.

Klein was granted tremendous control over the specific details of the project, considering his late entry into the overall endeavour. All of the engineering design, specifications, procurement of materials and components, and supervision of construction was carried out by Klein with Nazzer and the help of a few others from the NRC engineering staff.[224] Aside from the actual assembly on site at the Chalk River complex, almost all of the work was done at Klein's laboratory at the NRC in Ottawa or procured by it. He worked autonomously and almost entirely separate from the larger NRC program in Montreal and from the major engineering and construction work underway at Chalk River.

One reason that ZEEP moved ahead with such autonomy was the fundamental requirement that it not interfere with the schedule for construction of the larger Canadian reactor.[225] Even though Cockcroft had conceived of ZEEP as a useful step in the development and testing of the NRX design, he had to assure both Canadian and U.S. military interests that it would not encroach on the NRX work already started.

This was clear because the smaller reactor only went ahead after Cockcroft had secured an incremental and discrete supply of heavy water from General Groves' Manhattan Project over and above what had been budgeted for the NRX. Some people still thought that Cockcroft was splitting his efforts and taking away from the focus on NRX, but he apparently recognized, upon his assumption of overall leadership in the Canadian nuclear program, that the shortage of supplies might delay NRX anyway and that an interim step was viable. The NRX, in fact, did not become operational until 1947.

Consequently, Klein and the others working on ZEEP had the combined luxury of building a simpler, less ambitious device and, seemingly, without an absolute time pressure even though it was obvious that success would see ZEEP in operation and producing experimental data months ahead of NRX's completion.

The low energy feature of the ZEEP design not only meant limitations on the quantities of fissile materials and heavy water, it also meant that this reactor would not need many of the other design requirements that would be essential in the NRX. ZEEP would not need any provision for removing heat, would not need a great deal of shielding to absorb radiation, and would not need elaborate control and safety equipment.

But one feature that was essential was flexibility.

A key issue that remained to be fully addressed in early 1945 in the design of the NRX, despite extensive research in Montreal and lessons learned at an already operating

U.S. heavy water reactor, was the specific "lattice". The lattice is the term used to describe the size, shape and composition of the uranium fuel rods and their arrangement and spacing within the heavy water.[226]

If ZEEP were to contribute to the resolution of this problem, it would need to have the capacity to be easily altered with respect to the arrangement of the fuel rods.

Klein, Kowarski, and the team would address this challenge by designing and building a novel frame across the top of the ZEEP heavy water vessel from which uranium rods could be hung in various configurations.

The vessel itself was to be an aluminium cylinder of about two and a half metres high and two metres in diameter.[227] Although they knew that a spherical shape would make for the most effective reactor, a cylinder of roughly the same height and diameter carried many of the same advantages and fewer of the engineering headaches. Simplicity again. This vessel was built under the direction of Klein's lab where such components were tested and integrated with specialized pumps and control systems. Pumps with precision flow measuring instruments were needed as the heavy water was to be moved from storage tanks into the reactor as the means of edging it toward "critical" status.

Klein not only oversaw and participated in the work in his lab in Ottawa, he supervised the installation of the reactor equipment on site in Chalk River where the vessel was surrounded by large blocks of graphite that would act as a neutron reflector protecting the researchers and strengthening the device.[228]

The reactor also featured one significant safety device: a set of small cylinders of cadmium that were suspended over the tank. They would stand ready to drop into the tank, absorb neutrons, and stop the nuclear reactions if necessary.[229] It was a very exacting project filled with many restrictions and requirements not found in other engineering work.[230] Thanks in large part to the leadership and skills of Walter Zinn, a Canadian living in Chicago, the Americans had already built the first operating heavy water reactor by 1945 and, of course, had several years experience in graphite reactor technologies.[231] Klein would know of the U.S. device, but the Americans would share virtually none of their engineering technology with him. Much of what Klein and his colleagues were doing for their specific device demanded world firsts in technique and design.

Many of ZEEP's components had to be specially made in Klein's workshops, and Klein needed to develop specific, new emergency control systems. The seemingly routine welding was made challenging by the need to work with very thin walled aluminum tubes that would not interfere with the fission, but would still meet the precision needs dictated by the containment of uranium slugs.[232]

Even if they had been navigating in well-charted waters, the speed and steadiness of their work would have been impressive simply because of the challenges of wartime supply shortages. ZEEP also encountered an ironic labour problem.

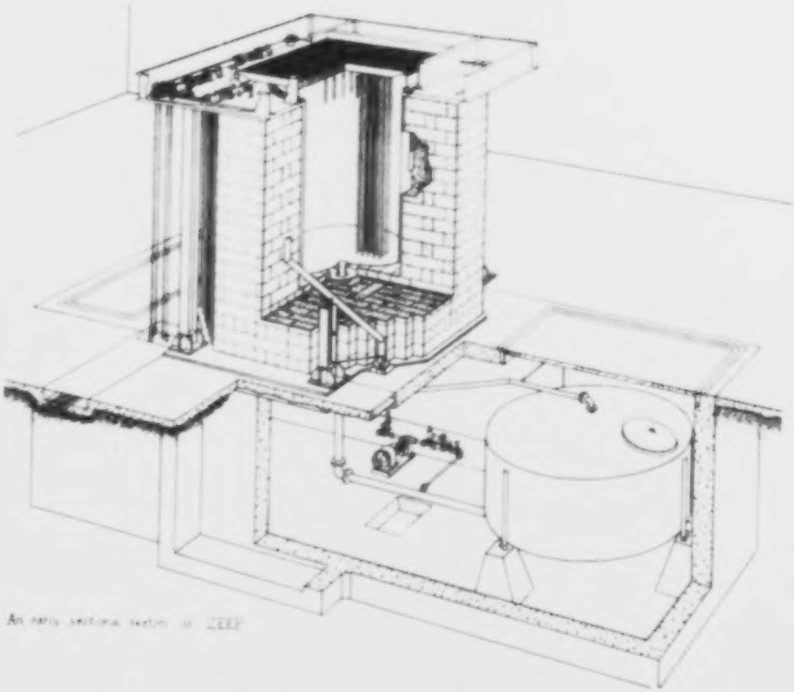
By the time Klein was ready to install the ZEEP vessel and equipment at the Chalk River site, a major factor in the construction schedule for it, the NRX, and the rest of the complex was the availability of what was called "common labour". Hundreds and eventually thousands would work on building the research complex and associated town site in nearby Deep River. The demands of the war continued to limit the number of young men available, and it was understood that those in charge had become increasingly less particular. The appearance of some of those arriving on site and receiving quick security clearance to work could have magnified any embarrassment Klein might have felt over the delays in his own security approval for the project in 1944.[233]

In any case, a more serious issue was the quality of the work. But in the end, aside from some minor delays and issues such as the need to clean and re-clean some equipment, nothing insurmountable developed.[234]

ZEEP was completed within eleven months of the first firm decisions to proceed, and less than nine months from the time that Klein was personally given a full go ahead to start work.[235]

ZEEP goes Critical and the Cold War begins

On September 5, 1945, George Klein and about two dozen colleagues watched intently as heavy water slowly pumped its way up from a storage chamber into the ZEEP vessel and a small spot of light moved across a scale signaling that Canada's first nuclear reactor had come into operation at Chalk River.[236]



Cross Section Drawing of the Klein-designed components of ZEEP, Canada's first nuclear reactor *(AECL)*.

Klein was also staring into the face of the arms race.

The modest celebrations that day ended with a house party to which some friends and family members including Klein's wife Florence (who had met Kowarski before and was visiting relatives in Pembroke near Chalk River that day) were invited.[237] The inclusion of family members was illustrative of a relaxation around security issues as well as a desire to share the general feeling of accomplishment.

For many of the Canadian scientists, who were to use ZEEP for their research in the years ahead, and for those who were still facing major challenges in the NRX project, it was only the beginning. ZEEP was to become a very valuable for other research as well as for performing physical measurements and sorting material for the NRX design.

It was soon operating 24 hours a day and was only shut down a few years later in order to free up its heavy water for NRX. It was restarted in the 1950s and remained operational and productive for close to two decades more.

There would be lots of nuclear history ahead for ZEEP, Canada, and the world.

But for many, there was a sense that day that a job had been finished, and even before this day arrived, Klein had felt the fading of one era and the dawning of another. The War in Europe had ended in March, and the Europeans working with Klein were feeling pressure to return home and help with the rebuilding. Brits like Cockcroft and the French nationals, who counted Kowarski and Halban in their ranks, would, in fact, be leaving the Canadian experiment behind.

In July 1945, the U.S. exploded the first atomic bomb at Alamagordo, New Mexico and followed it with Truman's ultimatum at Potsdam and finally Hiroshima and Nagasaki in August. Rumours that the Americans had the bomb and were intending to use it circulated quickly after the New Mexico event, and Klein claimed later that he, in fact, knew that the bomb was to be used on Japan a few weeks before it was.[238]

It is likely that he did. The scientific network was heavily wired at this time, and efforts were being mustered within it to stop the bomb and urge that it be demonstrated, not used.[239]

When it was used, it ended World War II abruptly, and although the feeling of relief in Canada and elsewhere was tinged with horror, the real news for most of Klein's family and friends was the Japanese surrender and the realization that the War was really over.

There was no obvious discomfort at NRC over Canada's role in the event, and, in fact, Cabinet Minister C.D. Howe supported by senior NRC people held an immediate news conference to tout the Canadian contribution to the bomb and to make public the associated assemblage of scientific and technical brain power on Canadian soil.[240] It was a period of celebration for most.

Klein, however, could not rest during the month of August 1945. He was in the final stage of his project, and rather than relieving pressure, the evolution of world events and the pull on key members of the team magnified the push to get the ZEEP job done.

While his assistant Nazzer and other NRC engineering staff had made their major contributions to ZEEP in Ottawa, Klein, who was also responsible for the actual construction of the reactor on site in Chalk River, still had challenges in putting the uranium metal rods clad with aluminum in place and ensuring that all parts of the device, particularly the plumbing that would carry the contaminant free heavy water, were clean.

Finally, up to the last day, changes were still being made to the instrumentation used to measure the neutron flow and the reactor's power level. The last step was the slow addition of the heavy water.

The Canadian scientists on the Chalk River team had predicted the level of heavy water required for ZEEP to reach critical status, and there was great anticipation as it approached. Although, in the end, it took a few drops above the predicted levels, they were essentially right, and the first nuclear reactor to begin operation outside of the U.S. worked.

ZEEP, with Klein's design and components, would not only provide data and products for the large-scale NRX reactor and other Canadian projects, it would also influence nuclear energy developments around the world. Kowarski would emulate the Klein design in France where he would construct a duplicate dubbed ZOE as that country's first reactor. ZOE (Zero Oxide Eau Lourde) which was constructed in the old prison at Châtillon went critical on December 15, 1948. Cockcroft would return home to assume the head position of the U.K.'s first national nuclear laboratories at Harwell where he would help oversee early nuclear development in Britain. A low energy reactor — the UK entry to the nuclear field called GLEEP — was built there before the end of 1947. Other countries would also learn from ZEEP and the people involved in it.[241]

In 1951, JEEP, yet another low energy reactor which did not try to hide its relationship with ZEEP, would be built by a partnership with the Netherlands in Norway thus bringing at least the intellectual core of the Norsk Hydro original heavy water cans back home.

To the extent that ZEEP contributed to Canadian reactor development over the next quarter century, Klein's influence continued to flicker within the growing the industry. It was a period when Canada assumed a major international role in nuclear medicine, research, and power under the auspices of Atomic Energy Canada Limited (AECL), a crown corporation developed from the NRC Chalk River Laboratories. Nuclear energy became a major source of electric power in Canada, and it employed thousands of highly skilled people.

Klein's direct involvement waned as he moved on to other challenges that demanded his specific, technically skilled problem solver talents. He did serve on early Advisory Committees that helped establish the profession of nuclear engineering and continued to visit the Chalk River site to provide counsel and share his experience for several years thereafter.[242]

But September 5, 1945 marked the beginning of the end of his personal involvement in the field. It also is a date that many see as the start of a phase of human history coloured deeply by the fruits of projects such as ZEEP.

On that date, evidently by mere coincidence, 200 km down the Ottawa River in Canada's Capital, a clerk at the Soviet Embassy defected taking with him evidence of Soviet espionage, notably in Canada, around nuclear research.[243]

The defector, Igor Gouzenko, would identify people associated with the Canadian project as having helped Russian scientists in their efforts to develop the technology.[244]

Alan Nunn May, a British scientist who had worked in Canada as part of the multinational team, would be arrested in London within six months of September 5, 1945 for having conveyed a sample of nuclear materials to the Soviets.

For some, the Gouzenko affair and thus the date of September 5, 1945 have greatest meaning as the symbolic start of the Cold War and the arms race it inspired.

May, who would receive a 10-year sentence[245], was the life of the party playing piano and singing at Chalk River that night.

He was also among the small group standing with George Klein earlier on September 5, 1945 watching ZEEP when it went critical.[246]

Chalk River site circa 1980 *(AECL)*.

"katakartanaq: snow with a hard crust that gives way under footsteps.
aniugaviniq: very hard, compressed and frozen snow.
pukak: crystalline snow that breaks down and separates like salt.
qiasuqaq: snow that has thawed and refrozen with an ice surface.
qiqumaaq: snow whose surface has frozen after a light spring thaw.
apijaq: snow covered by bad weather.
apigiannagaut: the first snowfall of autumn.
kavisilaq: snow roughened by rain or frost.
kinirtaq: compact, damp snow.
mannguq: melting snow.
masak: wet, falling snow.
matsaaq: half-melted snow.
natiruvaaq: drifitng snow.
qannialaaq: light-falling snow".
Inuktitut Words for Snow[247]

6. THE SEEDS OF SNOW

The aboriginal people of Canada's Arctic have many words for snow. Some interpretations suggest that the number could be put as high as fifty. Canada's Department of Indian Affairs and Northern Development identifies at least fourteen words used by the Inuit to describe substances that people in the South might simply call "snow".

Rather than adding undue complexity or gratuitous colour to the language, these words are efficient and practical. When two syllables like "pu – kak" can be used to convey the nuanced image of *"crystalline snow that breaks down and separates like salt"*, there is clear evidence of a useful and well-honed means of communication: terminology that has been polished, survived an evolutionary epoch, and gained wide acceptance.

The people of the Arctic need these words. They are indispensable tools in a world where snow in its various forms defines the quality of life. When two hunters meet, it is of little use for one to tell the other that he has just crossed fields of snow or that snow fell recently. But if he describes the texture, the strength, and the water content, he is sharing valuable, potentially life-saving information on the difficulty of walking, sledding, or tracking game.

Words. Short, descriptive, clear, and unique. These are the natural products of many years and many thousand conversations in the cold North wind.

Over the past century, snow has become more and more important to science. Partly driven by the technological needs of the transportation, construction, and energy development that have combined to open up more of the snow-covered world, scientists have recognized an increasing need to study snow in depth and with greater distinction.

Like the Inuit hunters, researchers also came to recognize that they needed a common, but finely graded language if they were to share their experiences or learn from colleagues. Having something important to say without the means of communicating it to others can seem like a mute scream. For many years, scientific research in many disciplines was muffled in this way by the absence of a common language and basis for snow research.

Just as it would be difficult for Inuit hunters to convey with hand gestures and knowing looks the meaning of "apigiannagaut" to someone who did not understand Inuktitut, researchers meeting in international conferences without specific, agreed-upon definitions and measurements would have great difficulty in attaching anything truly meaningful to references of "wet", "fluffy", or "crusty" snow or even hail and slush. The word snow itself can be taken to mean either a mass or an individual flake.

George Klein was one the many researchers who faced this problem in the 1930s and 1940s and helped address it. Klein did not start out to become an expert in the mechanics of ice and snow. He was more concerned with immediate, practical problems snow posed for aircraft ski research, construction projects, and vehicle design. But he realized that his work was impaired by the lack of a generally accepted system for ground-cover snow classification.

Test results gathered in developing new logging equipment, railway machinery, construction materials, vehicle designs, and many other technologies depended on the specific snow conditions. But there was no systematic and trustworthy way of measuring and describing the snow conditions at the time of the tests or experiments. The need soon became obvious.

Klein's response, characteristic of a personality that recognized few hurdles as insurmountable, was to make up his own system, design his own instruments for snow measurement, launch the first national snow survey in Canada,[248] and advocate that others around the world do the same. Klein became Canada's leading expert in snow cover physics and mechanics, and one of the key and uniquely influential figures in the creation of the international system of classifying ground-cover snow, and, through this, one of the fathers of the decades of snow-related research and development that followed.

Growing International Interest

To fully understand why Klein devoted himself to developing a snow classification system and how he succeeded, it helps to realize that he was not alone in the quest. This not only helps to explain the appeal of the challenge, but the reason that its conquest was appreciated so broadly.

The history of invention is spotted with stories of brilliant innovations that arrived and faded before "their time". The technical infrastructure and, sometimes, the human receptor did not exist. The seed, the bright idea, found no fertile soil and never took root. A successful innovation, on the other hand, is often an unwitting participant in a strange race that sees the victor carried forward on the shoulders of potential competitors. Just as the idea is taking shape in the mind of one person, the need for it, and thus the seeds of the same invention must be developing in the minds and the works of others, preferably many others. Only in this way will it be widely appreciated to eventually "take root" and succeed as an influence on the world.

Fortunately, and somewhat predictably, as George Klein was struggling with his own limited understandings of snow mechanics related to his transportation research, others were encountering similar challenges and developing a coincident desire to understand more about snow. Even more people around the world were simply frustrated by the impasse that snow presented in their daily work and lives.

In Canada, there had been some early 20th century studies in physics involving ice, but wide interest in the scientific and engineering implications of snow and ice did not receive a real boost until the celebrated Polar expeditions of adventuresome Norwegian, American and British teams. The voyages led by men like Amundsen, Scott, Peary, and Schakleton were dramatic, a little theatrical, and highly publicised.[249] Canada, as the venue for treks to the North Pole, was on the frontlines for much of the Arctic adventures and touched by the innovations they inspired.

Ironically, however, it was at the other end of the Earth that a Canadian, a Toronto-born physicist named Charles S. Wright, later Sir Charles, gained fame and made a special contribution to the early exploration of snow and ice. He was what would eventually be regarded as "the glaciologist" on the doomed Scott "Terra Nova" expedition to the Antarctic.

Wright, who was part of Captain Robert Falcon Scott's core team, did not make the final leg to the pole, but was part of the group that found Scott's frozen body in 1912.[250]

Wright not only survived, but drew upon his long hours of ponder and frozen experience to help produce the first book in English on the field of "Glaciology":[251] the study of ice on landmasses as opposed to ice in the sea or weather-related studies of snow.

Years later, Sir Charles, by then a renowned researcher in other fields and the Canadian who had served as Chief Scientific Advisor to the British Admiralty, would return home to Canada to join a uniquely Canadian assault on the issue of snow science in the wake of World War II.

During the decades in between, the British Glaciological Society, partly a product of Sir Charles Wright's work, was established as the first organization in the world of its kind. The Society was founded by Gerald Seligman, a scientist with a special concern for safety and author of the classic study "Snow Structure and Ski Fields" in 1936. Seligman, like Sir Charles, would also become one of the important and influential figures in George Klein's snow research.

Despite being home to such pioneers, Britain was far from being the only other country interested in snow. Switzerland with its intense concern over avalanches, Russia with its great frozen expanses, and Scandinavia with its cross-country skiers were other regions with long-standing interests in snow. Each had made unique contributions to the world's growing, albeit limited, understandings of snow in the early part of the Century.

By the end of World War II, Germany was also considered a source of snow-related innovation. Its conquest of Austria and Czechoslovakia led its armies into snowy mountain passes and into a need to develop new snowplough technologies during WWII, and prior to the War, a researcher in Japan studied snow crystals in special detail even developing new laboratory equipment and processes for growing crystals artificially. This and other work produced insights into the relationship between the form of the snowflakes and their rate of growth.

In North America, a particularly mesmerizing contribution to early snow research was made by W.A. Bentley of Vermount, who worked over a 40-year period from the late 1800s to the early 1930s to produce a massive collection of thousands of snowflake photographs. A book of his photos entitled "Snow Crystals" stood as the best publication and collection of its kind for many years.

Much of the early study of snow in the U.S. did not, however, involve microphotography or any sophisticated examination of snow at the level of fine detail. It was done with sticks and other simple, crude tools to measure depth and other rudimentary features of the snow cover.

These studies sought to predict the spring run-off around mountainous areas, largely in the west, and fed into the growing discipline of hydrology and the work of organizations such as the Western Snow Conference. Meteorologists were also developing their own tools and systems to measure falling snow and features of specific interest to their field.

Sir Charles Wright, a member of Capt. Robert Falcon Scott's Antarctic team, with Klein's colleague Lorne Gold at NRC in 1960s *(NRC Institute for Research in Construction photo)*.

Even though it was not sophisticated physics or chemistry, these hydrological and meteorological surveys were systematic and the source of an impressive body of empirical evidence that hinted at the possibilities of further, deeper study.

And there were other undertakings and reports around the world. Like all pioneering science, they seemed to raise more questions than they answered and created a need as much as filling one.

Klein Senses the Problem

George Klein was, therefore, far from being alone in the 1930s and 1940s when he realized that more needed to be done in the study of snow. Like a child who knows almost instinctively what kind of snow makes a good snowball or a skier who knows that a ski that performs best in cold dry snow can be a disaster in wet heavy snow, Klein and other scientists sensed the increasing importance of the snow conditions to their work. Yet Klein also knew that he had no scientific way to record or measure the conditions in the way needed.

Unlike young snowball makers or skiers who are satisfied to simply know when snow conditions are good or bad, Klein also wanted to know why they were good or bad because he wanted to point the way to better research and better engineering design.

George Klein was thinking about people like ski makers, vehicle manufacturers, and construction engineers when he decided to take his work to another level and develop his own, original system for measuring and evaluating snow conditions.

He made his first attempt in the late 1930s, and, in fact, the report he presented on his aircraft ski research at the conference in Washington in September 1939 also constituted an interim report on his first studies on snow conditions. Had German armies not launched their invasion of Poland that same week, Klein might have returned to Canada emboldened by the reception his paper received to renew this aspect of his work with new enthusiasm. But he did not have the luxury of following this snowy trail to the end for many years.

Instead, he and his engineering design talents were absorbed for the next five years by a string of minor tasks as well as major projects such as the nuclear reactor construction. Aside from some follow up on the ski research for military applications and his work on the *Weasel* all terrain vehicle, Klein's snow-related research had been put on the shelf along with other interests for the duration of the War.

But he never dropped his desire to deal with the problem nor did he abandon the thought that he could develop a snow cover classification system to meet his needs.

Early in 1945, unexpectedly and even before the end of the War in Europe, thoughts of peacetime reconstruction brought about a new opportunity for Klein to resume his work. NRC and other government agencies were starting to think cautiously, but hopefully about uplifting ideas such as post-war economic growth and booms in housing, transportation, and food production. Those in charge knew that for Canada, many of these challenges would involve confronting snow.

The NRC President, C.J. Mackenzie, was projecting his mind ahead to peace and such Canadian needs when he proposed the creation of a new national Associate Committee to focus on soil and snow research issues in 1945.[252] For much of its history, efforts to pursue NRC's research priorities were mobilized by a portfolio of such Committees. More than learned advisory boards, the Committees often were empowered with modest budgets and, more importantly, with mandates to serve as national fora for experts to make contact, share ideas, and build consensus.

Thus, in the last year of the War, NRC moved to establish a new Associate Committee to consider what was expected to be an increasingly important issue: the mechanics of soil and snow. Initially struck to address military problems, the Committee soon expanded its perspective and started to intertwine with the interests of another NRC Associate Committee: the one on Geodesy and Geophysics. The latter was strengthened by a longer history and established links to international bodies of influence.

George Klein's expertise on snow was in demand by both of these Committees, and this manifestation of growing interest in snow science combined with a renewal of his ski research gave Klein the opportunity and motive to undertake something new and ambitious. He initiated a series of field studies in an effort to gather more data and begin filling in holes in Canada's snow research.

Canada's National Conference on Snow

Klein's renewed snow studies and the interests of the two Associate Committees converged on the 17th of September 1947 when a special joint Conference on Snow and Ice was convened in Ottawa. The Conference, the first of its kind in Canada, was a venue for experts to report on new efforts, seek resources and solicit support for the next stage.

The Conference would turn out to be an important gathering in the history of Canadian science and engineering.

Sir Charles Wright, who was by then back in Canada and acting as consultant to NRC and others, was an honoured guest.[253] But he was not alone as a distinguished and influential figure in attendance. The Chairs of the two Associate Committees, who were also co-chairs of the conference, were men already recognized as leaders in their fields and fated to become giants in Canada. University of Toronto civil engineer Dr. Robert Legget, the Chair of the Soil and Snow Committee, had a keen interest in construction issues, had the respect and ear of the NRC President, and had a vision that would influence research and life in Canada.

Legget's Co-Chair was John Tuzo Wilson, the leading Canadian geophysicist who was responsible for the first glacial map of Canada, pioneering aerial exploration of the North, and the international promotion of Plate Tectonics and continental drift theory.

Their joint 1947 meeting attracted a wide variety of snow interests. They ranged from academics such as the Director of the Meteorological Observatory at McGill University to industry people such as the entrepreneurial son of Arthur Sicard, the Quebec inventor of the snow blower. The participants also included a number of senior officials involved in transportation, agriculture, geology, and weather research. They had impressive positions and daunting titles such as Director of the Arctic Institute of North America, Chief Geologist of the Geological Survey of Canada, and Dominion Field Husbandman of the Experimental Farms Service of the Department of Agriculture.

The meeting also included an NRC engineer, George Klein.

They talked of troubles with snow fences and snow ploughs, run-offs and floods, skis and sleds, frozen soil and frost on plants, clothing and housing, avalanches and snow slides. Many issues were raised, and many projects were proposed.

But all of the discussions and project proposals pointed to a common path, the need for research and a greater, deeper knowledge of the physical and mechanical properties of snow.

Even those who had been studying snow conditions for years felt the need for more science and methodology. The Comptroller of Water Rights for the British Columbia Department of Lands and Forests reported, for example, that even though a great body of empirical data on snow cover and spring run-offs had been amassed along with a network of dozens of "courses" for snow surveys in Canada and the U.S. there were still questions that could not be answered and great inconsistencies in the prediction ability from region to region.

When George Klein was invited to speak, he too could report on extensive tests and study related to his specific interests of aircraft skis and transportation, and he too would punctuate his presentation with the same conclusion that "more must be learned about the properties of snow".

But Klein was also able to say that he was already doing something about it.

He told how he had not only started a program of collecting snow information, but was also in the process of developing a new system of snow measurement. He had even designed his own "test kit" of special instruments for measuring the physical and mechanical properties of snow.[254]

Klein conducting field work in snow research *(NRC Archives)*.

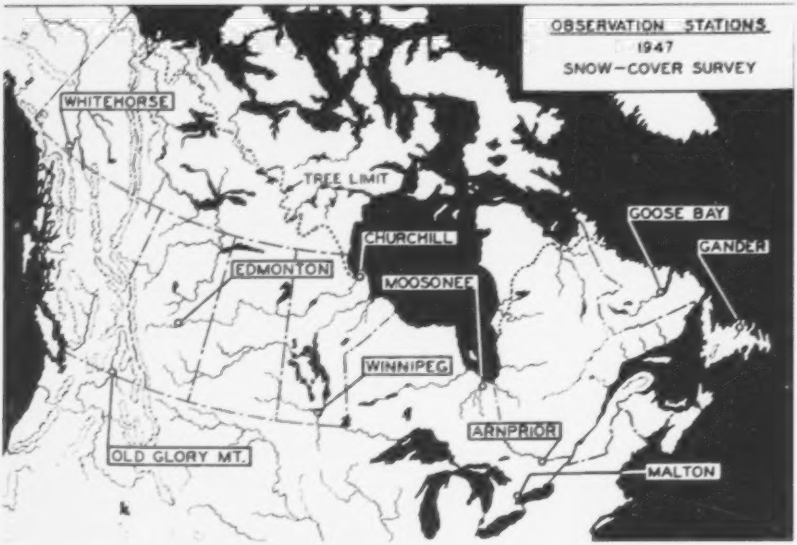
Klein had designed the kit to make it easier to measure hardness, depth, and surface qualities. For this, he needed simple tools like gauges, sticks, and photos.

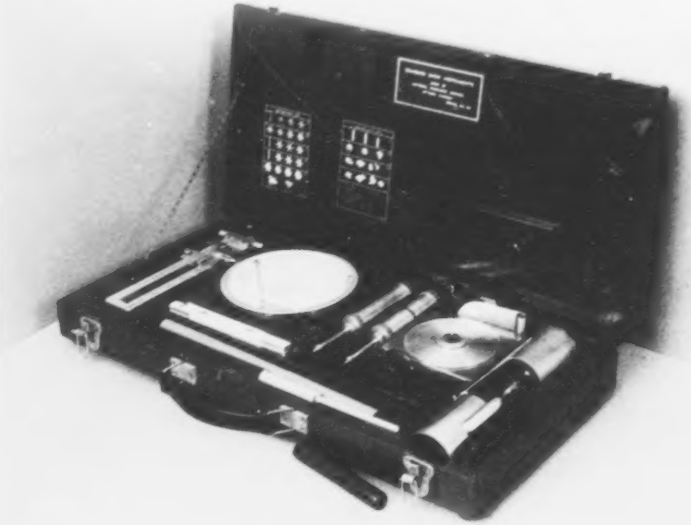
But Klein also looked at snow in a more complex way than this might suggest. He looked at it as a scientist looks at any material. He recognized that the overall physical properties that any substance expresses are a function of things going on inside and set out to measure these things inside and relate them to the way the snow behaved.

In the 21st Century, nanoscience strives to study and alter materials at the atomic level. Yet in the 1940s, snow research was at a stage that still struggled to comprehend the large-scale relationships between water, ice, and air. Just establishing the relative proportions of each provided a step forward in describing the characteristics of a given pile of snow.

To Klein, this meant measuring the specific gravity (ratio of the density of a substance to that of a standard substance, in this case snow to water) and estimating the free water content or what we might consider "real water" molecules in the snow. The first is a simple matter of melting, measuring volume, and weighing, and Klein explained that the second measurement could also be achieved through a simple process.

But it was one based on some complicated understandings.


OBSERVATION STATIONS
1947
SNOW-COVER SURVEY
WHITEHORSE
TREE LIMIT
GOOSE BAY
GANDER
CHURCHILL
EDMONTON
MOOSONEE
WINNIPEG
ARNPRIOR
OLD GLORY MT.
MALTON



Klein's "Snow Kit" and map of first Canadian snow survey *(NRC).*

Drawing on his knowledge of thermodynamics and statistics, Klein had generated the rough formula that he called "a simple calorimetric method" to estimated the amount of free water in the snowball. It was based upon how much snow was needed to change the temperature of a given pot of hot water by a given amount.

In equipping himself for his work, Klein saw that it clearly made sense to have a supply of thermometers on hand. Certainly, the temperature itself can be logically linked to the quantity of water versus ice in a snowball since the lower the temperature usually meant more of the latter.

Temperature, therefore, by itself, was an appropriate piece of basic data.

As Klein thought about snow in this way, he put together the list of needed tools in his mind. In addition to his thermometers, he would need a scale to weigh the snow, knives to cut the snow, gauges to measure pressure, a cup to scoop, a spatula, and a magnifying glass. Things anyone could find in a kitchen or, at least, in the NRC engineering workshop.

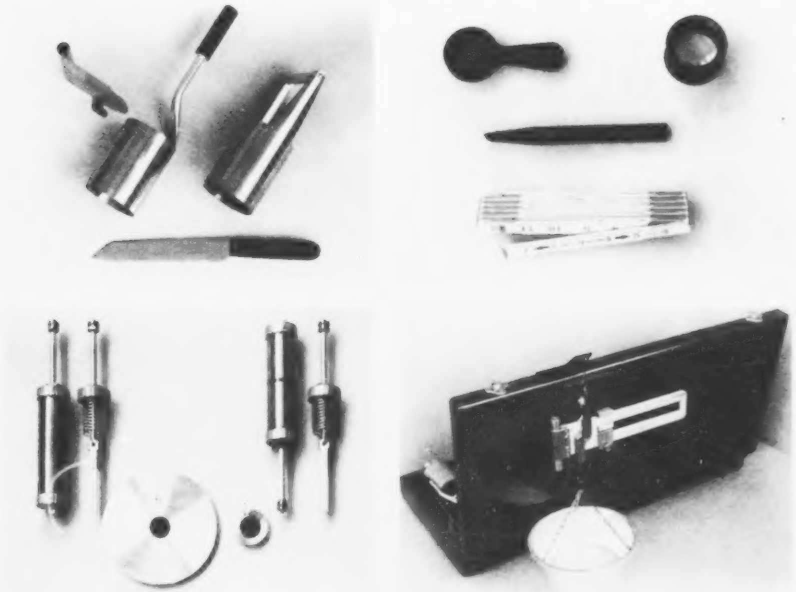
He could have used existing equipment. But he didn't.

Klein approached problems not by thinking about what could make do, but what would be ideal and then by figuring out how close he could practically come to it. He made his own tools. Instead of simple knives or scoops, he designed a special snow cutter that had a handle that made it easy to rotate the blade in a way that avoids compressing the snow and altering the measurements. He made a special cup with circles engraved on the bottom with radii that increased one millimetre at a time. It was a cup, a simple device, but one that instantly measured the size and shape of grains of snow.[255]

Even when he used existing instruments such as spring gauges to measure snow hardness, he recognized the need for special corrections to improve the measurements by considering the impact of different angles or different layers, and he developed tables to interpret this data.

Klein's tools were novel, ingenious, and useful, but the data being sought was not that unusual. Klein's tools measured obvious features such as specific gravity, hardness, temperature, and "free" water content, as well as the size and shape of individual grains of snow. Yet Klein's tools were efficient and effective and easy to use. His kit was portable, and one of a kind.

As a neat package, the Klein Kit for measuring snow would become a minor force on its own. It facilitated and promoted snow research not only in Canada, but was beginning to have an influence abroad. Although NRC



The Snow Measuring Kit was many little inventions in one *(NRC)*

was not a manufacturing concern, the demand for the snow kits was such that NRC found itself making them as a sideline business for many years selling dozens to military and civilian researchers in the U.S. and other countries. Even at the time of the 1947 snow conference in Ottawa, the Klein instrumentation was already being used by experts in Switzerland prompting Klein to adopt the metric system from the outset in anticipation of more foreign interest.

Klein welcomed the occasion that the Conference provided as an opportunity to demonstrate his kit and techniques, but more importantly he appreciated the venue to speak because he needed the endorsement and support of others if he was to succeed.

He was an employee of a research division, the NRC Division of Mechanical Engineering, that did not immediately recognize snow science as its responsibility. The Division embraced laboratories and facilities filled with machines, gears, and metal. Klein had been drawn into snow as a consequence of his involvement in the Division's aeronautical work, and while he enjoyed the support of his Director, Parkin, there were many competing demands for Klein's ingenuity and talent for invention within the Division and within NRC. If he was to follow through on his snow research, he needed the strong pull of forces from outside.

One of those forces was provided by the Conference Co-Chair Legget, who had travelled to Europe after the War to tour construction laboratories. This tour took him through Swiss snow research centres that impressed him so much that he had even commissioned a special report on the Swiss research for Canadian use believing that Canada lacked this special knowledge.

But Legget and Parkin's support would not be enough. Klein needed the active involvement of outside organizations and individuals.

Klein wanted a methodical, consistent inventory of the physics of snow cover conditions right across Canada. He wanted to couple his advice to the aviation industry, the military and others on the importance of snow conditions with reliable and meaningful information on what those conditions might be in key sites across the country. He needed to conduct tests simultaneously in many locations on a regular basis and in a systematic, professional way. He could not do it alone.

He needed lots of help.

The military had assisted by testing out Klein's instruments in the course of its special northern exercise "Musk Ox" in the mid-1940s.[256] But Klein really needed people with some technical expertise, permanently stationed in a number of cities and towns. Fortunately, the best candidate, the Meteorological Service, was at the Conference and agreed. The Service, which had people located at airports and other locations across Canada, conscripted its staff to conduct the winter-long measuring work at ten sites, mostly airports, but also at Old Glory Mountain in South Eastern British Columbia near the U.S. border.[257]

Even though the Service had facilities and people in the regions already, it was still be being asked to do a lot. The Klein snow surveyors had to dig pits or trenches about a metre square and very deep: right to the ground. Then these "volunteers" would have to jump in order to conduct their measurements and tests. They had to collect data that not only reported on the surface snow, but each underlying layer. The Meteorological Service teams had to conduct the tests in largely unsheltered areas and often open country.

Some fieldwork had already been started by the time of the October 1947 snow conference in Ottawa. Klein was, therefore, able to share some data and observations. But it was preliminary, and he not only used the Conference to solicit more help from his federal government colleagues, but others in the private sector and provincial governments as well by demonstrating his kits and offering them up to anyone who might be interested in casting the net farther.

This first-ever such Canadian Conference on Snow and Ice ended with the conclusion that work needed to be done on specific issues such as snow fences, snow removal, aircraft and sleighs, but the fundamental consensus was on the tandem need for research "on the basic physics of snow and ice" and for "observation stations and snow surveys" with "a better correlation and distribution of uniform data".[258] Klein had succeeded.

It was in this atmosphere of agreement and support that George Klein went ahead to complete Canada's first national snow survey.

An International Conference to Focus on Snow

The innovation and development driven by the War, and the opportunities opened up by peace were, of course, felt, not only in Canada, but also around the world, and these influences extended into scientific disciplines embracing snow and ice. Consequently, just as the Canadians were wrapping up their special gathering on the issue in late 1947, they received word of an intriguing event to be held in Oslo, Norway in the Summer of 1948 in connection with the General Assembly of the International Union of Geodesy and Geophysics (IUGG).[259]

The IUGG is one of dozens of non-governmental, umbrella scientific bodies that serve international science.

As the "Geo" of its name suggests, the IUGG is dedicated to the international coordination of scientific studies of the planet Earth. Like its fellow scientific "Unions", IUGG is hugely influential in setting the ground rules for research in the physical, chemical and even mathematical aspects of everything from the shape of the Earth to the behaviour of volcanoes. It is also concerned with the oceans, the seas, the atmosphere, and their cycles as snow and ice.[260]

The Union comprises seven international associations, each responsible for specific topics and themes. The IUGG also, from time to time, establishes special Commissions that link the work of the various associations and other international organizations. Like the Olympic Games, the IUGG holds its General Assemblies as special world events every few years.

In 1948, as the Union prepared for its "Olympics of Geophysics" in Oslo, Norway, one of the newer of its seven constituent associations was then the International Association of Hydrology (IAH). The IAH had become, during the pre-War years, an arena for a growing international interest in snow and ice issues, and it had taken on the mantel of leadership in promoting research and encouraging co-operation. The Association, thus, announced that its contributions to the upcoming Oslo congress would include the staging of an International Conference on Snow and Ice. Canada's standard bearer at this event was to be George Klein.

The news of the upcoming Oslo conference presented Klein with an opportunity to share his work in a way that might encourage international co-operation and magnify its impact far beyond his initial expectations. Interest in his snow kits and the support of the Canadian conference added to the excitement. He entered the winter of 1947 with renewed enthusiasm and the prospect of great things in mind.

As Canada's inaugural national snow survey continued for a second year that winter, fieldwork and data collection was coupled with a review of the previous year's findings in a drive to deliver something useful and influential to the coming Oslo meetings.

If he was right, Klein thought, his work was, if not compelling or novel, at least a symptom of something grander, a greater need, and the prospect of an international collaboration to attack the lack of scientific understanding. He wanted to share the results of his survey internationally, not merely to table new data, but to encourage even more research.

He felt certain that he was onto something unique. The only other large-scale, systematic snow studies that he knew about were still meteorological measurements of falling snow and hydrological Spring run-off surveys of river basins, both of which were often focused on simple measurements of quantity. One research program that did touch upon Klein's special interest in the physical characteristics of snow on the ground was the avalanche work in Switzerland.

Yet even Swiss experts had recognized some of Klein's methods and tools as an improvement on their own systems.

Klein was confident, but he knew that one issue remained unresolved.

How to "Measure" the Shape of a Snow Crystal

Even with his creative imagination and access to well-equipped workshops, one problem stumped him. One special feature of snow did not lend itself to easy measure. This was the shape of the individual snow crystals.

When there is an infinite variety and no two snow crystals are thought to be the same, the idea of describing them in a routine, technical way would seem complex at least, if not impossible. It seemed more art than science, and Klein would have to find a way to merge the two.

For an instant, he may have wondered whether there was any need to record the shape of the snow crystals for there was at the time no real evidence confirming that this mattered. But he knew that cold snow that has just fallen is feathery and lighter than it is after it has settled. After settling, the air has been pushed out increasing the density, but, more interestingly, the grains of snow have often bonded into disfigured blobs. This not only adds to the size of the individual grains, but also to the weight and the strength.

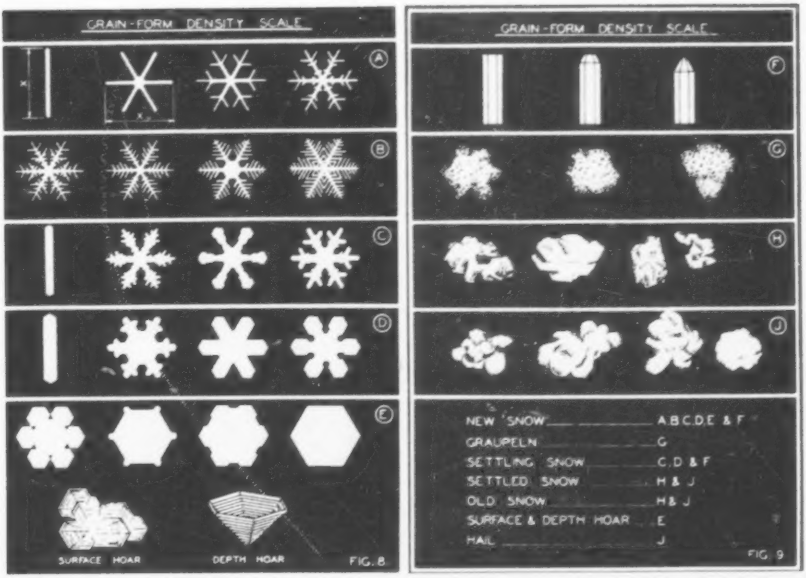
Klein reasoned that the feature that could bring the two worlds of snow shape and scientific measurement together could be found in the density of the crystals or grains of snow. Density was a feature that would affect the overall snow conditions, and density could be related to general shape of the crystals. Certainly, the more compacted they looked, the more dense and structurally sound they were likely to be.[261]

Klein now recognized that his purpose (describing snow conditions for research) did not require a method of classifying all possible features of snowflakes and snow grains. All he had to do was to create relevant categories of "compactness" that were easy to use in the field.

He set out to develop a table that was a simple yet comprehensive way of identifying the "compactness" a given grain of snow. Reserving his imagination for the technical challenges, Klein resolved to give his table the insipid title of "Grain-form Density Scale".[262]

Most of the reports and measurements generated by Klein's snow kits were dominated by numbers: square centimetres, grams, and degrees.

But this thing — "The Scale" — would have to be more poetry and pictures. It would need to include drawings of snowflakes and terms like "feathery", "slender", and "soft", speaking more directly to a human experience with snow even though it is one that focuses upon a single grain. Yet, Klein would have to resist romantic or clever names for categories of snow since they could be misconstrued by preconceptions or past usage in other


GRAIN-FORM DENSITY SCALE
A
B
C
D
E
SURFACE HOAR
DEPTH HOAR
FIG. 8
GRAIN-FORM DENSITY SCALE
F
G
H
J
NEW SNOW ____ A.B.C.D.E & F
GRAUPELN ____ G
SETTLING SNOW ____ C.D & F
SETTLED SNOW ____ H & J
OLD SNOW ____ H & J
SURFACE & DEPTH HOAR ____ E
HAIL ____ J
FIG. 9

Klein's Snow Scale - poetry and art as much as science *(NRC)*.

disciplines such as weather monitoring. He decided instead to assign a letter to each of what would eventually be a total of nine (9) classifications in his table (A.B.C.D.E.F.G.H. and J – skipping the confusing, number-like letter I).

His choices and decisions were arbitrary, but practical.

Still, just as the dimensions of a cubit was first set using "the length of the arm from the elbow to the extended fingertips" as deemed by the "royal master", it matters less what the standard is than whether it can be referenced easily and whether it becomes widely accepted.

In this regard, Klein's categories had to match types of snow crystals that could be quickly recognized in the field and in all weather conditions using an ordinary magnifying glass.

Most school children know how tricky it is to catch a snowflake and how quickly it can be lost under someone's warm breath or touch. Yet most children can describe a snowflake. They know that it is white, looks like a star, and always has six sides. But they probably do not know why, and they may be surprised to learn that while there is basic truth to their image of an individual flake, ground-cover snow does not always look this way under a magnifying glass.

Snowflakes form generally through transformation of water directly from vapour to solid around a dust particle that takes place when a cloud passes below the freezing mark: its water turns to ice crystals. Water molecules, as the triumvirate of two hydrogen and one oxygen atoms, bond with one another into the six-sided hexagonal shape almost like a series of adjacent, equilateral triangles would come full circle into a hexagon. The process continues on and on as other freezing water molecules bond along the path of least resistance to give us the ultimate, relatively large-scale, symmetrical, hexagonal shape of the snowflake. The many surfaces of the crystals and the flakes scatter the light leaving what we see as pure white.

That's the straightforward process of making snow.

But George Klein and others knew that the life of a snow crystal is not always so simple. Temperature, wind, density of the dust particles, and water content of the air can all affect the rate of growth and general evolution of the crystal, its voyage to the ground, and its ultimate size and shape.[263] The crystals can look like a star, a plate, a rough needle, a column, a column with a plate at each end, or what is known as a dendrite, a feathery shaft that is something in between a column and a star.

Klein also knew that there would be no easy answers or ways to predict the kind of snow grains he might find. New snow sometimes has the same grain forms as settling snow and old snow sometimes acts and looks like hail and ice.

Indeed, Klein may have even had to remind himself that he was not required to look for only snow crystals and flakes, but also hail and ice since they too fell to the ground and made up part of the snow cover. His original quest, after all, was to understand the entire physical conditions of the snow cover and to better understand the framework for designing skis and equipment.

Consequently, Klein's table, his "Grain-form Density Scale" included descriptions of sleet and ice as well as the now well-known types of snow crystals. His nine categories were

(A) the slender "needles" which would placed in the same category of density as new snow crystals of very delicate flakes with few branches on their six rays; (B) the slightly more dense "plane" (flat) crystals of new snow placed for this purpose with crystals covered with hoar frost (sublimation on the crystals); (C) slightly denser plane crystals along with the grains of partly settled snow; (D) even more dense plane crystals and settled snow – visibly denser and thicker (E) Crystals so dense that they appear as hexagonal plates and depth hoar (crystals that look like little cups and are the kind that form to create false cavities in the snow cover and avalanche threats) (F) crystals in the form of long columns not flakes (G) Graupel, a snow crystal covered with rime (an ice coating); (H) Old settled snow that is blob-like, but still has crystal faces (J) old settled snow that does not have crystal faces.[264]

Klein was inventing a kind of language for ground-cover snow research.

Terms like hoar, rime, crust, and old snow generated by other researchers were not always helpful. Meteorologists, glaciologists, skiers and other students of snow had "not been in complete harmony… (and often) …The same term (could be) used by different groups, or in different localities, to describe entirely different forms of snow".[265]

Klein's system did not ignore these words, the images of what they referred to, and techniques used by others, but he when he used them, he did so in creating clearly defined categories of snow relevant to mechanical properties such as strength and substance. He made it simple and saw it used by many people in many locations over the winter of 1947 in locations from Gander to Whitehorse, and it worked.[266]

The World Adopts the System

When Klein sat down in June 1948 to write his presentation for the important Oslo Snow Conference of the International Union of Geodesy and Geophysics, he was able to say with compelling evidence that his system provides "a great deal of general information about snow and the variety of forms in which occurs on the ground", that his results "clearly demonstrate that surveys of this kind yield data which can be of considerable assistance to both users and designers of winter equipment", and that a lot had been learned about "snow conditions on exposed areas across Canada".[267]

Klein had shown, for example, that the conditions around airports, usually unsheltered areas, were hard, and predictably so, in fact, as hard or harder than that found in the wind swept "Barrens".

Practical information and testimony to the value of the survey.

More interesting to Klein's international audience than his specific Canadian findings was the fact that his system produced useable results at all. He had clearly developed a system and approach that worked, and as a bonus, he had developed the tools to do the job easily and effectively. Others echoed his interest in snow data.

He clearly made an impression on his audience. The "seed" which had "long been germinating" — the idea of an international system of snow classification – "took root" at the 1948 Oslo Conference. The meeting concluded with a decision by the International Commission on Snow and Ice to set up a special three-person committee with instructions to produce what was hoped would be "the generally accepted international system for classifying snow".[268] The U.S. and Europe were represented on that committee along with the intriguing Canadian, George Klein.

By 1951, Klein and his Committee colleagues had refined their techniques, crafted a draft scheme, and consulted with corporations, government agencies, and individuals from around the world. A formal proposal was tabled that year, and after a few amendments, final approval was given by the Commission on Snow and Ice of the International Association of Hydrology for the publication of the first-ever document on "The International Classification for Snow". The foreword to the document was written by Seligman himself citing George Klein and his two colleagues for "the debt we all owe" them.[269]

In the end, the final version of the world's first approved system for the classification of snow passed through many hands, but it echoed Klein's own words and ideas quoting directly from his original report on the Canadian surveys and addressing all of the issues Klein raised in his own work: specific gravity, free water content, grain size and strength. It also included an alphabetical table of classes of "grain shape" as it pertains to the density and strength of snow.

It was a shorter list than Klein had originally used, reflecting increasing knowledge of what was most relevant. But it covered all the same bases.

Klein had succeeded again. He applied his ingenuity and perseverance to a challenge that sometimes required measuring the obvious and minor improvements to established techniques as well as genuine innovations. His success was also a function of the support of others: Legget and Parkin at NRC and people like O.M. Solandt, the Chair of the Defence Research Board, and Andrew Thomson, Controller of the Meteorological Service of the Department of Transport.[270]

This support and the national collaboration it expressed allowed Klein and his colleagues to stage a large-scale demonstration project in the per-

Klein and colleagues at Oslo Conference that led to first International Snow Classification System *(Klein family photos).*

fect test conditions: Canada in winter. The dramatic demonstration combined with a practical package of innovative ideas and techniques that were shared openly and freely with a ready world.

Only the imagination could ever capture the impact that this work has had internationally. Even if the snow classification system had only been used by Klein's immediate colleagues in the international bodies he served, it would have most certainly affected industry, public safety, and societies in many countries.

Engineers, geophysicists, and hydrologists over the decades will have consciously or unknowingly used the system, or at least the data and discoveries of others who did, to design most of the transportation systems, buildings, and consumer products that serve the snow-covered world. The original system has been improved and refined over the years, but like most fundamental products of science and technology, its impact is pervasive and ever expanding.

Perhaps, the best way to describe its impact is through the developments in Canada. Legget, the civil engineer and Co-Chair of the first Canadian snow conference, was recruited by NRC to establish its Division of Building Research in the late 1940s and predictably, his interest in snow and acquaintance with George Klein influenced his approach to the task.

Legget oversaw the development of national construction research in Canada during the post-war boom and a tremendously important period in the history of Canadian building during which the annual value of Canadian construction was doubling every five years and reaching into many billions of dollars.

Much of this building took place in frozen areas of the North and was made possible by Legget's researchers and new programs in snow-related geotechnical work and building design for snow loads. He even established a specific Section for Snow Research whose inaugural employees Don Pearce and, later, Lorne Gold grasped onto George Klein's work as a baton as Klein moved onto challenges more aligned to the world of gears and metal in his mechanical engineering labs. Other work by the Division of Building Research would help combat avalanche threats when the Trans-Canada Highway was stretched through the Rockies.

To the extent that Klein's influence was felt through the Division of Building Research alone, it contributed to a better life for all Canadians.

The Division assumed responsibility for, among other things, the development of Canada's National Building Codes. The NRC Codes, a product of a federal organization, do not carry the force of law because building regulation in Canada is a provincial and municipal responsibility. Yet the National Codes have the strength of a strong research base and a grand consultation process that have combined to make them compelling models that were eventually incorporated into legislation in every province, territory, and municipality in Canada.

The impact is such that the Newsletter *Construction Innovation* could assert on the Division's 50th anniversary that "it is safe to say that any Canadian who lives in a house, drives down a highway or crosses a bridge, has been touched by (its) internationally respected work".[271]

When Canadians do these things in snow, they are being touched by the work of George Klein.

"the infirmities affecting so many of my limbs
while I am still so young (mean that) ...
I cannot even earn a few cents for the comforts
that would make life more enjoyable
for myself as well as my wife and child
... for I have only one arm and not a good one at that,
the bones of the elbow having been shattered
... because of this, everything must be at my hand ..."
Quadriplegic Veteran
April 24, 1955[272]

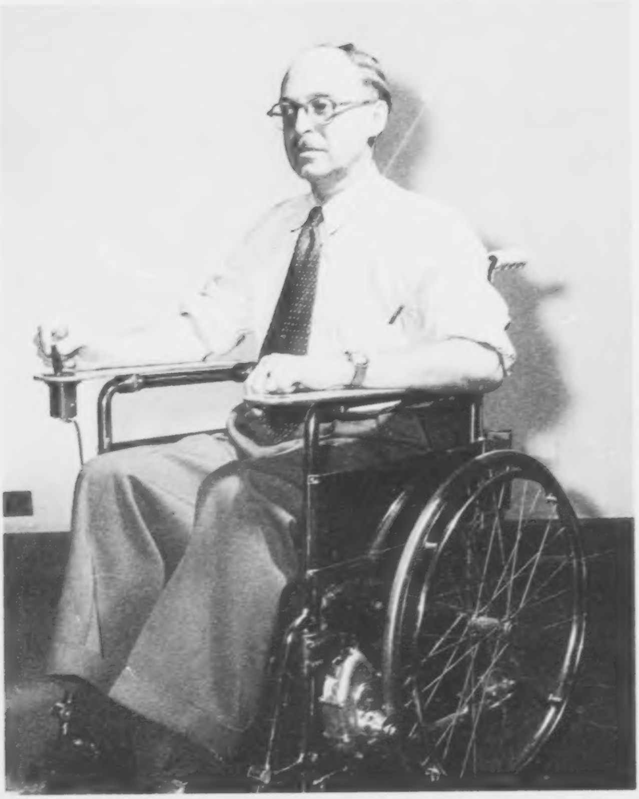
7. THE FIRST WHEELCHAIRS FOR QUADRIPLEGICS

George Klein invented and built what was likely the world's first practical, electric wheelchair, specifically designed for quadriplegics.[273] The "Klein Chair", as it was known,[274] was not only a "Splendid Invention" and a technical success,[275] but also an influence in changing the character of scientific research, in creating a new engineering discipline, and in fostering a new era in the paradigm of societal attitudes toward the disabled. The impact of Klein's invention is still evident in rehabilitation research and motorized wheelchairs today.

The explanation of how Klein came to play this role lies in the force of special, heroic personalities and in uniquely Canadian attitudes that placed a high value on the invention yet gave it away freely without the protection of patents, registered industrial designs, or legal agreements.

These forces came together in an unexpected way in the late 1940s, the wake of World War II, to make it the right time period for such an innovation and to make Klein's engineering laboratories in Ottawa the likely venue for it.

Klein and his research colleagues were just starting to put the frantic pressures of World War II behind them. In fact, for many people, the War had begun its journey down the dusty road of history and its influence was moving just beyond the horizon of immediate thought. NRC scientists were either looking for ways to develop commercial and industrial applications for their wartime military inventions or for longer term challenges in fundamental science.



George Klein sitting in a completed electric wheelchair for quadriplegics – the first of its kind in the world *(NRC)*.

When the wheelchair project eventually arrived on Klein's doorstep in 1950, it would be a sharp reminder of the relatively recent end of the War. Yet the project actually reflected events decades earlier.

A Crucible for Innovation for the Disabled

In fact, they began in an important way in a foreign country in the late 1920s. It was just about the time that young George Klein arrived in Ottawa to begin his own research career when thousands of kilometres and an ocean away in a laboratory in England, researcher Alexander Fleming observed the "funny" bacteria-killing potential of penicillium molds. Although Fleming soon published his findings, it would take almost ten years more before others picked up on the daunting challenge of refining and growing it in a useful form. The leaders were at Oxford: Australian Howard Florey and German-born Ernest Chain who would later share the "penicillin" Nobel Prize with Fleming.[276]

Through their experiments, the Oxford team took the process and application of penicillin mold treatments beyond the petri dish and mice to humans. Their amazing results combined with the immediacy of the threatening war in the late 1930s to convince U.S., and later Canadian, interests to make the investments necessary for mass production in time to help front-line soldiers. Millions of units were produced and used in WWII battlefields around the world.

Every war adds its own unique contribution to human suffering. The U.S. Civil War produced thousands of "empty sleeves and wooden pegs",[277] and World War I added a staggering new feature to humanity's invalid population with those affected by gas and the tuberculosis-breeding trench warfare.[278]

World War II also created tens of thousands of injured veterans and civilians who could not escape daily reminders of their experience. But World War II will always remain remarkable: it induced a dramatic change in both the numbers and the perceptions of victims of conflict.

Because of the new antibiotics, more of the injured survivors of this war would be paralyzed.

Only a few years before WWII, most injuries that produced paralysis and many that prompted extensive amputation were fatal because they also involved or induced urinary tract infections, bed sores, or other complications that could not be controlled nor even detected until too late. But introduction of the new treatments in coincidence with the violence and injury of the War meant that, more than ever before, a paralyzed soldier might be expected to live to consider and confront the implications of his paralysis for the greater part of a normal lifetime.

During World War I, less than two out of every ten Canadians and Americans who sustained spinal chord injury would ever return home and survive for any length of time. In World War II, those numbers were essentially reversed; nearly 90% made it home, and only a tiny fraction would die later as an immediate result of their injuries.

Paralyzed veterans of World War II also differed from their civilian counterparts and military predecessors in what he might expect from their country and the world. The natural, albeit glacial, evolution of humanity in the treatment of the disabled was magnified in the post-war period by an atmosphere of relative affluence and gratitude.

Whereas the First World War spawned an ironic and bitter economic depression in Canada and other countries, the Second World War was punctuated by a period of prosperity that included a healthy national economy and level of government revenues. The Canadian government, for one, had done a much better job of paying its bills throughout the second war and faced a manageable financial situation in the post war period.[279]

For many of George Klein's NRC colleagues, this prosperity meant job opportunities in private industry, universities, and other research organizations. Those like Klein that stayed at NRC had stable jobs and some freedom to pursue special interests and projects with a degree of thoroughness not allowed in the midst of war.

For Canadian veterans, national prosperity was manifested, in part, in improved programs to support anyone who wanted to attend school, invest in a home, buy a car, and, for some, to adapt to life in the wake of disabling, battlefield injuries. The Canadian government through the Department of Veterans Affairs stood out as active and inventive, even considered "rare" in comparison with its counterparts in other Allied nations, in the degree to which it sought to serve its veterans in the late 1940s and early 1950s.[280]

It would be easy to overstate this "generosity" and the hospital care afforded disabled veterans. Yet in an international context and a historical sense, it was better in Canada in the late 1940s and early 1950s than might have been expected. Canada, in fact, became a crucible of unique pressures, opportunities, and partnerships during this period that made it possible for world firsts in rehabilitation technology to bubble out of it.

Many forces combined to create this phenomenon and to encourage Canadian innovation, but as is often the case, if not always, this step forward for humanity was a consequence of the commitment, vision, and passion of individuals.

One was Dr. Harry Botterell. A neurosurgeon in Toronto before the War, Botterell had already emerged as one of the very few physicians anywhere who believed that victims of spinal chord injuries could not only be saved, but could be treated to the point of returning to productive and rewarding lives. Botterell developed a team approach that emphasized proactive medical and nursing care and physical retraining as a package without seams and with a shared goal of rehabilitation.[281]

With the outbreak of the War in Europe, Botterell was sent with his innovative techniques, dedication, and reputation to the Canadian Military Hospital in Basingstoke, England.[282] He was there at Basingstoke when the wounded arrived from the horrific and doomed Canadian-led raid at Dieppe in 1942.[283] One of these soldiers was to have an impact on the treatment of spinal chord injuries that would rival Botterell's own. The patient was Lieutenant John Counsell. Counsell not only received Botterell's medical treatment but also admonishment.

Counsell, whose family's wealth gave him some comfort and security, was told that he had the privilege of returning home, disabled, but in a position to push for better treatment for others. He listened and acted upon the advice.

By 1945, this paralyzed veteran and an impressive group of disabled colleagues, medical leaders, and supporters had founded the Canadian Paraplegic Association, the first association of its kind anywhere in the world, unique in its focus and belief that paraplegics could lead useful, reasonably normal lives.[284] The Association also stood apart from other veterans groups in that it provided services and advocated for civilian paraplegics.

By this time, Botterell was also back in Toronto and in the position of director for neurosurgical services at the Christie Street Military Hospital. From this post, he established an associated residence, a unique facility as the first rehabilitation centre for spinal cord injury in Canada: Lyndhurst Lodge. Botterell and Dr. Al Jousse, a disabled physician chosen to be Lyndhurst's medical director, would become committed champions in the then difficult and daunting movement to focus treatment on the "return (of) the patient to independent life beyond the confines of hospital or paraplegic colonies" arguing among other things that depression among paraplegics was most often the result of the loss of independence and meaningful participation in community life.[285]

These three men, Botterell, Counsell, and Jousse, and their organizations were largely responsible for making Canada an unusual and powerful environment for innovation in the treatment of the disabled in the immediate post-war period.

The Department of Veterans Affairs, which was the federal agency charged with funnelling the Government's response to these pressures, also had effective and committed champions, notably Major C.A. Bell, the Department's persistent and dedicated Director of Prosthetic Services in Ottawa. Bell and later his colleagues at the Sunnybrook Hospital in Toronto would act as the fulcrum that helped lever the technical expertise in George Klein's NRC laboratories with the power of a special need and uniquely Canadian advocacy.

Wheelchair Technology Before Klein

One of the first expressions of this combination of pressure, need, and willingness to spend money on veterans was the wider availability of a new generation of convenient manual wheelchairs.

Throughout most of World War II, wheelchairs were still generally regarded as a tool for hospital staff to transport patients from one room to another not as a personal item for every disabled patient. A hospital might have a handful of chairs to serve as many as a hundred patients, and if an early-rising patient got hold of it in the morning, he might monopolize a chair for the entire day.[286]

Chairs with wheels date back thousands of years. Still, they were not widely available prior to this century. The disabled of the Middle Ages might have been fortunate to belong to a family with a wheelbarrow. Anything resembling a modern wheelchair was only available to the very privileged,[287] such as the King of Spain who had one specially constructed in the 15th Century for his personal use in dealing with the gout.[288]

Patents were filed for certain wheelchair inventions in the 19th century, and functional personally propelled wooden wheelchairs were available to most institutions in the early 20th Century.[289] An issue of Popular Mechanics in the 1920s even reported on disabled people using electric scooters for their personal transport.[290]

But the first major development in the history of wheelchair technology — the one that would benefit WWII veterans and establish the context for George Klein's invention — did not come about until the 1930s. This was the design and manufacture of lightweight, folding wheelchairs using tubular steel and special mechanical components. These chairs, while not powered by electric motors, meant real independence for many people for the first time. They were not only easier for a patient to propel with his own muscle and will, but to fold, to put in a car, and to manoeuvre.

They were popularized by two American inventors, Harry Jennings and Herbert Everest. Their work best illustrates both the technical and social setting of George Klein's later work.

According to their company's publications, the Everest & Jennings enterprise started like many American technology business legends, in a small garage in California. It was just outside of Los Angeles in 1933.[291]

Herbert A. Everest, a mining engineer, had been paralyzed as a result of a mine accident over a decade earlier. Although he did have his own personal wheelchair, it was a heavy, wooden block that restrained a man whose desire to enjoy life like able-bodied people had not been diminished. A friend and neighbour, Harry Jennings, not only sympathised with Everest, he also shared his love for devices and invention also being an engineer. Together they built what is generally regarded as the first folding, tubular steel wheelchair, filed a patent and launched a business that would eventually come to dominate the international market for wheelchairs.[292]

Together they created a tool for mobility and freedom that would touch the lives of disabled people around the world.

As with penicillin, the invention of the Everest and Jennings (E&J) chair and the requisite gestation of patenting, development, and manufacture seemed to fit perfectly with the timing of WWII. Throughout the 1930s, the firm no doubt struggled to build a business with a limited market of limited resources in a very limited economy.

But it survived to be positioned for the need that the first half of the 1940s produced. E&J wheelchairs were, it appears, popular from the beginning.

Because of his well-connected friends, the Canadian John Counsell was among the first paraplegic WWII veterans to learn of the E&J chairs, to recognize the benefits, and to get one for himself. Consistent with his mission to advocate for others, Counsell soon travelled the country demonstrating and promoting the manual chair's manoeuvrability to those with the resources to supply them to others: the federal government.

A determined and committed role model for disabled veterans, Counsell did not accept the idea of a wheelchair easily as it symbolized confinement and a surrendering to the permanency of paralysis. But these concerns were secondary to his desire to do whatever made it feasible to participate fully in "normal" life. He had a lot of respect and a lot of clout.

As a direct result of John Counsell's advocacy and promotion, the Canadian government made a mass purchase of 200 E&J chairs. It was the American firm's first major order for WWII soldiers and a turning point for the firm that would give Canada a special place in the company's history. The U.S. Red Cross and other organizations would follow within a short period with orders in the thousands. Meanwhile, Counsell and his friends had started to look at even more challenging needs and even more novel technologies.

Canada and the Electric Wheelchair

Initially, the idea of electric wheelchairs was not high on their wish list.

It is not that the idea failed to cross their minds. Motorized transportation for the disabled, in one form or another, had been around for many years prior. Officials in the Department of Veterans Affairs even had established a formal position on the use of electric wheelchairs as early as February 1946.

But it was negative.

As one memo to the Deputy Minister stated, the general feeling at the time was that "a machine of this kind was not required in the hospital ... (and that a) propelled chair, careening around the wards and corridors, might, and likely would, cause some unfortunate accident".[293]

Even the DVA's Major Bell, who tried to be open minded on such issues, considered the idea of motorized wheelchairs as impractical in the first years after the War calling the available chairs a "menace to seriously disabled patients under existing traffic (and) ...climatic conditions (in Canada with its winters)". Bell felt, in any case, that most disabled veterans were more interested in getting cars or trucks with hand controls.[294]

These suspicions were largely confirmed in consultations with medical staff like Botterell and patients represented by John Counsell. But Counsell felt that everyone deserved some chance at mobility and that the door should be kept open since "some unusual circumstances might arise which would call for this type of Chair and ...the individual case could be considered if and when it arises".[295]

This was generally the international view as well.[296] Electric wheelchairs did not work very well and, even though there was some feeling that seriously impaired individuals could someday benefit from them; the technology was not sufficiently advanced. The U.S. Veterans Administration in Washington told the Canadian officials, for example, that only " one battery-operated (wheelchair had)... been tried out at one of (its) Paraplegic Centers", and it was not "suitable or satisfactory for use by paraplegic patients". The Americans promised to advise the Canadians if they ever found a motorized wheelchair that really worked.[297] But they would not have the opportunity. The Canadians would develop their own chair first. It took a few years, but attitudes did change. Just as John Counsell suggested, some cases could not be helped with the standard manual wheelchairs, and the idea that a motorized wheelchair might be useful after all took root. Before the end of the decade, Canada would see its first serious attempts to construct such as chair.

Again, experimentation would be driven by John Counsell's group and by the willingness of one disabled individual to take a chance. The patients essentially took things into their own hands not only in volunteering to try out the chairs, but also in supplying the equipment themselves. In May 1949, Lyndhurst Lodge Director Jousse reported that he now knew of at least one patient "operating a wheelchair with a motor provided by the Canadian Paraplegic Association" and that he had heard of a firm in Chicago making motors that could work on an E&J chair.[298]

"I believe (now) that the electric motor for propelling a wheelchair should be made available for quadriplegic patients who are totally incapable of propelling themselves", Jousse said adding that this view had the support of John Counsell".[299]

A few months later, Major Bell asked his Acting Deputy Minister to amend the anti-motorized wheelchair Departmental policy noting the "Issue of motorized outdoor wheelchairs … to a quadraplegia veteran …". Bell pointed out that an Ottawa firm was ready to supply "a suitable type of motor attachments to Everest and Jennings folding chairs".[300]

In 1949, the Department of Veterans Affairs thus began its own officially sanctioned experiments with motorized wheelchairs in a modest attempt to help its quadriplegic veterans. George Klein would say years later that the Department, in fact, "obtained a number of (the) electric drive attachments" for this purpose from an American "handyman mechanic", whose drive system was the first that could propel wheelchairs carrying quadriplegic patients even though it did not work long and had mechanical problems.[301]

They, in fact, had many problems, and the Department soon turned to NRC, the organization that had helped the military so much during the war, for assistance. The Department said it wanted something completely new and different. It was natural for the NRC Mechanical Engineering Labs to receive such a request from a branch of government associated with the military. The Labs existed almost entirely as a result of service to the military. Before the War, it had less than 40 people on staff. By the end of the War, this figure had risen to 170.[302] Throughout the war, these "research" labs grew almost exclusively in response to calls for help from the armed forces. It was technical problem solving work, but the Division was effective and successful, and it would have been almost automatic for the Department of Veterans Affairs to think of it first when confronted with a technical challenge in serving quadriplegic veterans.

Yet while Veterans Affairs officials were ready to provide needed services for the clients, the Department would not jump on the opportunity to develop something entirely new if a suitable alternative could be purchased off the shelf. As illustrated by its groundbreaking purchase of the E&J chairs, the Canadian Veterans Affairs staff were well aware of new rehabilitation technologies and how to access them and, therefore, would not have even considered the adventure of developing a complex motorized, electric chair if any effective foreign-made alternative existed at the time.

Major Bell and his colleagues had no viable options, but to support the development of something new and innovative. They could find no motorized wheelchair that really worked for quadriplegics in the world.

Klein is Given the Assignment

Bell specifically asked NRC to design an improved electric drive for wheelchairs for "quadriplegics and other patients having very limited manual capability". The NRC Mechanical Engineering Director, J.H. Parkin, later recalled the date of the formal request for assistance as December 1950 although the first informal inquiries likely came earlier in the year.[303]

Klein would have welcomed any assignment that was very focused and clear, consistent with his self-image as a technical problem solver. In this case, even the technical challenges were precise and the problem was set out simply. When the Department had tried out existing drives on E&J chairs, they broke down frequently and were very "difficult to maintain".[304]

Almost instantly, Klein recognized the two key problems with the previous attempts to create a workable chair, and he also saw solutions.

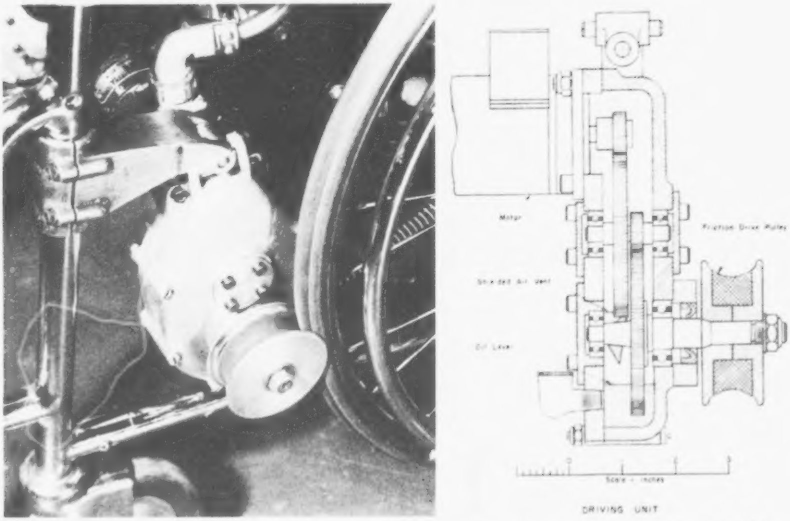
"After examining the existing drive, (Klein) concluded that an increase in the voltage of the electric drive from 6 to 24 volts would permit the use of smaller currents and thus avoid the rapid burning of switch contacts", Klein's boss Parkin would later recount. "And (Klein saw) that independent drives on the two main wheels of the chair should be used instead of a single drive for both wheels with its power transmission trouble".[305]

These initial observations would, indeed, turn out to be crucial, and Klein's solutions were sound. Yet he would take two years more to finish the project and complete his final report. The ultimate product would require many other smaller innovations, considerable fine-tuning, trips to hospitals, extensive consultations with patients, doctors, and government officials, and the trial and error of multi-faceted technical projects.

These small steps forward and back were inventoried in brief progress reports on the Wheelchair that were filed as part of NRC's Annual Review and in internal memos. But as the photos, diagrams, and words of Klein's 11-page final technical report would show, he was striving all along for a whole that was much greater than the sum of these individual tasks. Klein clearly wanted to elaborate a solution in a whole product that would serve as a model along with a manual on how to make the chairs easily and to keep them maintained.

Klein and his colleagues approached this project with a dedication and thoroughness that stretched well beyond what might have been expected.

Klein and his colleague Robert Owens, one of the key members of the team of technicians and engineers that helped perfect the wheelchair components *(NRC)*.



The Wheelchair drive system and other components were described in detail in Klein's report so anyone could replicate it *(NRC)*.

This was fortunate, as he needed patience and persistence. His two primary innovations precipitated many other adjustments and decisions as dominoes of engineering design. Klein, for example, achieved his 24-volt system by using two 12-volt batteries,[306] which, in turn, necessitated the design of a special box that could fit under the chair seat, and this special box had to be altered to provide adequate floor clearance, to avoid interference with the manoeuvrability of the chair, and to permit easy removal of the batteries for recharging.

The introduction of two drive units, on the other hand, led to an entirely new means of steering by engaging and disengaging the drives independently. While this erased the need for the complicated and constantly stressed steering mechanism of one drive, it now required new types of controls, new wiring, and new interfaces between the two drives.

The sum of the seemingly minor decisions, linkages, and adjustments would form the real issues and ultimately George Klein's unique contribution to the development of wheelchair technology and rehabilitation engineering.

Throughout this quest, both Klein, as a researcher, and his chair very much represented a balanced package of thoroughness and practicality. As

Klein worked away, he was not merely trying to quickly and adequately address a technical problem that had been dropped upon his desk. He was trying to design the very best machine for the purpose, and to do so in a way that made sense in the circumstances.

His thoroughness and desire to do his best were evident in his use of powerful aircraft motors in the drive. Klein and the NRC shops also designed and built a novel new gearbox specifically for his wheelchair. It had spur gears and a friction pulley driving each main wheel to better benefit from the reversible electric motors and to ensure consistency in the machine's speed. That speed was "2 ½ miles per hour". Even this quality, the speed, was defined through careful experimentation to find the optimum balance between safety and utility.

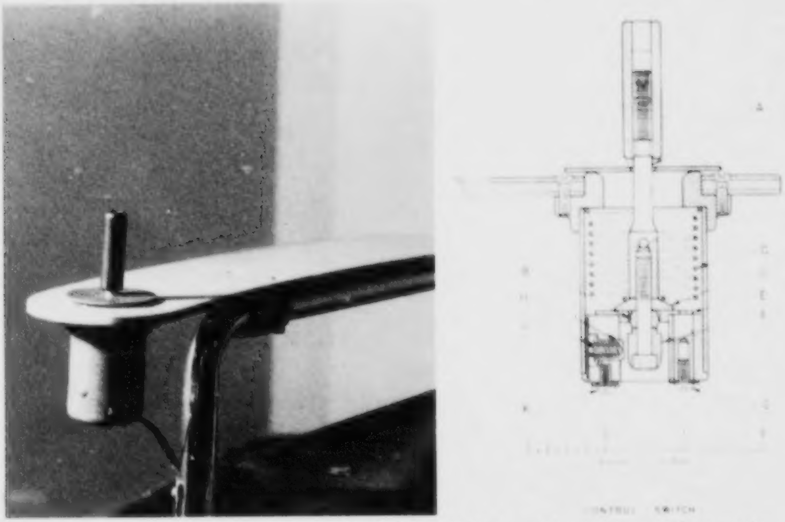
Klein also developed a unique new control switch that, in many ways, resembles the modern "joy stick". This alone was a very sophisticated improvement on the available control systems. It had eight different positions to take advantage of the full range of possible combinations of one or both motors driving forward, running in reverse, or disengaged. He even designed the control lever, which projected only two inches above the armrest of the chair, to permit the occupant to "feel the contacts". "If incapable of other action, (the patient) could operate the control simply by resting his wrist on the end of the lever".[307]

Each one of these seemingly minor innovations were tested and re-tested as discrete elements and in combination with others, particularly in the context of what patients wanted and what was comfortable for them.

Finally, after two years, it all came together in a working prototype that satisfied everyone including Klein.

It was clearly a whole device that functioned almost organically with its occupant and could not be adequately described in mere technical reports and diagrams. Even NRC administrators recognized this and decided to take the unusual step of producing a short demonstration film as a means of capturing the essence of the invention to promote and share it with others.

When the film was finished and shown, its images of the wheelchair in motion stunned viewers with the elegance of an obviously superior device. As an entity, it floated magically like a package that seemed to be a unity and a true extension of the human it carried. "The Klein Chair" was immediately recognized for its remarkable manoeuvrability that included very gentle steering qualities and a narrow clearance.



The joystick control system of the Klein Chair is still a common feature in electric wheelchairs today *(NRC)*.

It could operate in very close quarters ("1 inch"[308] clearance) and on relatively steep ramps (1 in 10 grades). It had a deceleration rate of "1.6 feet per second" which meant that it coasted about "4 ½ feet" from full speed to a full stop.[309] These performance features combined with an operating range of up to "20 miles" to make the chair practical for some outdoor uses even though it was designed and built for indoor use.

An immediate hit with the patients in Toronto because of its performance, the Klein Chair became even more popular because of its reliability. It was thus Klein's commitment to a vision of a new and novel whole device and not merely to addressing problems that the old designs presented that made his invention unique and worthy of the epithet "first in the world specifically designed" for a purpose.

It also warrants the title because it was practical.

Klein was thorough and detailed. But he did not go to unnecessary extremes.

There were many approaches that he rejected in deference to what would work in the real world of wards and limited budgets.

On occasion, for example, he identified techniques or materials that would have improved the wheelchair's performance, but only marginally.

and thus did not include them in his final design. "(Electric motor brushes) with a lower coefficient of friction were also tried, but the improvement was so small that (it) was decided to retain the original brushes", Klein noted in his report.[310]

Early on in the project, Klein also rejected the idea of building an entirely new chair opting instead to simply add his sophisticated drive and control system to one of the readily available E&J manual wheelchairs. Building the entire chair from scratch would have been defensible in a quest for perfection since the transportability and folding features of the E&J chairs were no benefit in a device encumbered by a motor, batteries, and equipment.

But from the outset, he wanted to create something that would be the very best it could be within the framework of what would make life easier for his partners in the Department as well as the patients. The chair would not, after all, be useful, no matter how sound and technologically superior, if it could not be easily and efficiently replicated.

By all these measures, it was clearly a success in Canada, which warrants a review in isolation of any broader, international implications. The project was, after all, undertaken with the specific purpose of helping the Canadian interests, the Department of Veterans Affairs, serve a small set of individual Canadians.

Despite this limited clientele, there were no limitations on the motivation Klein felt for the task. He was touched and motivated by this specific project and by those who would use the chair. Speaking on behalf of the staff and patients at Lyndhurst Lodge, Dr. Jousse once noted that he Botterell and Counsel were not only "favourably Impressed" by the NRC's "extremely ingenious design and assembly of the motor unit for the wheelchair", but also with Klein and his colleagues who " in addition to reflecting great ability, indicate that they have a very human interest in the welfare of these unfortunate and disabled patients".[311]

Klein clearly felt some special tie to this project. Even years after the formal "completion" when he had moved on to other responsibilities, Klein followed the performance of the chair and its future generations closely writing to users to suggest adjustments and improvements. He would notify users of new equipment suppliers or new ideas such as using "a small neon type lamp … because it would practically never require replacement" or "a fuse holder which can be removed by hand".[312]

By the spring of 1954, it had become clear that the "Klein chair" was outperforming its predecessors in many ways including in its need for repair and maintenance as well as its obvious power and maneuverability. In a report that says more about the frailty of the electric chairs previously available, E.A. Weir, the head of the Department's Prosthetic Services shop in Toronto reported that the "Klein Chair" had impressively gone "for almost two months" and "not a single mechanical or electrical failure has occurred in use on the ward".[313]

The chair was only being used, however, "at the rate of 10 miles a month, rather lower than we had expected". But the reason it was not racking up more mileage was apparently "due to the fact that Mr. Hutchinson" (presumably the main, if not sole, user of that first Chair) was now able to attend classes and thus sit in his chair at "school a larger part of the time" than before.

Weeks later, NRC, sensing that something important had been achieved with this inaugural chair, asked, through Klein, if the prototype chair could be temporarily sent back to Ottawa to show it off to "representatives of government departments and firms" as well as the general public during an "Open House" at the NRC Montreal Road Laboratories on May 26, 27, and 28" (1954). This request was made even though the special demonstration film was available and even though it was recognized that this "an inconvenience to ... Hutch (the patient) ".

The Government was soon convinced, and the Department of Veterans Affairs made the commitment to spend the money needed to build more chairs modeled on the Klein design. The chair and its new drive system had proven reliable, and the only question was the extent of the demand.

The perceived need for electric wheelchairs of this design was still limited to the number of Canadian quadriplegic veterans with the combination of severe disability but the capacity to still move the joystick. This was initially estimated to be "only a few .... 5 or 6, ... in Toronto". But Weir was so impressed by the Klein design that he went ahead with orders for motors and equipment to outfit up to 20 chairs at what was considered a significant cost for the times of roughly $500 each or a total of " $8000 on the project'."[314]

This decision to plan for 20 chairs with chronicled demand of much less was taken in part because of the "possibility of civilian requirements". While Dr. Jousse and Mr. Counsell were yet to explore this "other" Canadian market for the chair, their colleagues were already looking beyond Canada's borders.

In one sense, Canadians did not really need to manufacture and ship wheelchairs in order to export the technology since Klein's detailed technical report was effectively a manual for construction and maintenance. In any case, the NRC demonstration film was proving that it could tell the story of the technology and its potential within seconds. With the report and film under their arms, Canadian government officials began promoting the device during trips to other countries. They found that their counterparts in the U.S. and abroad were equally impressed by the machine and anxious to learn about the innovations it comprised.

A Gift to the World

The issue of whether foreign interests would want this chair for their own quadriplegic veterans was clearly answered over the next year.

"This design has proven very successful, and has created, one might say, world wide interest", Major Bell reported.[315]

The focus soon shifted to how best to ensure that Klein Chairs would be manufactured on a large scale to not only meet the needs of spinal chord injury veterans in the U.S. and other countries, but also civilians with varied disabilities. Bell was the wheelchair's chiet international promoter in the mid-1950s, and he was consistently met with enthusiasm.

> *"... I presented the report ... at a recent meeting of the Committee on Artificial Limbs in California. Members of the Committee were very much interested in this design and many complimentary remarks were made with reference to the performance of the chair as shown in the film".*[316]

> *"Dr. A. Thorndike, Director, Prosthetic & Sensory Aids Service of the (U.S.) Veterans Administration ... and members of his staff ... were very much interested. Copies of the report have already been forwarded to them ... he would like to receive a copy of the film in order that it might be shown at some of the U.S. Veterans Administration Hospitals".*[317]

> *"Capt. T.J. Canty, M.D., Chief of Amputee Service, U.S. Naval Hospital, Oakland, California, ... expressed a desire to receive a copy of the report ... The film ... certainly proved an excellent method of demonstrating the capabilities of the chair ..."*[318]

> *"Mr. George Bowler, Ministry Representative, The British Ministry of Pensions & National Insurance, has requested to be supplied with two more copies of the report ... Apparently, considerable interest was aroused in the previous report forwarded through his office to England".*[319]

Even in the first months of 1954 at the time that only one Klein Chair was in operation and with only the report and a short film to demonstrate the invention, Major Bell and his colleagues were attracting interest from potential manufacturers south of the border. This included a special request from the very company that had pioneered the modern, collapsible manual wheelchair: Everest and Jennings.

> *"... (we) showed the film to members of the staff of the Everest & Jennings Company, 1810 Pontius Avenue, Los Angeles, Calif., ... this firm might possibly be greatly interested in subsequent manufacture ... Mr. Jennings and staff were greatly interested and expressed a wish for a copy of the (Klein) report ..."*[320]

During this period everyone seemed to accept, without discussion, the view that because the Canadian market for such devices was limited and partly satisfied by the Government, no Canadian company would consider its manufacture. The notion that a Canadian-based firm might manufacture such a product aimed at the international market did not seem to enter into consideration. In the 1950s, Canadian manufacturers that did serve international markets with novel products were usually branch plants of U.S. or other foreign interests and received their mandates and technologies from abroad. The ordained solution to mass producing the Klein chairs, apparently, was to find an American firm to do it.

By the summer of 1955, the interest in the "Klein chair" among civilians in Canada and among disabled Americans had reached the point where the U.S. Veterans Administration decided to help their Canadian counterparts identify "some industry in the United States to take up the manufacture".[321]

The Canadians welcomed the opportunity because they wanted to publicize the availability of the technology as widely as possible, and the parties decided to stage a high-profile event that would be trumpeted in a national news release and international communications.

The event was to feature the formal gift of one of the "Klein chairs" to the U.S. government as a symbolic sharing of the technology with the

Klein, standing at the back, with colleagues from NRC and Canada's Department of Veterans Affairs and the proto-type chair to be donated to the government and the people of the United States in 1955 *(NRC)*.

world. The gesture even had to be approved by the Treasury Board (a Committee of the Canadian Cabinet), but apparently not because it involved the gratis transfer of a valuable Canadian invention to the detriment of Canadian industry, but because the chair was considered a government asset as a collection of parts and materials.

The submission to the federal Treasury Board sought approval to "authorize the Department of Veterans Affairs to arrange for the presentation to the United States Veterans Administration of an Everest and Jennings wheelchair complete with motorized unit, valued at approximately $500 ..."[322]

Approval was given, and on October 26, 1955 the special ceremony was held at what was then "the new" Veterans Memorial Building in Ottawa. The Minister of Veterans Affairs, Hugues Lapointe, formally presented a "Klein Chair" to the government of the United States. The gift was received by representatives of the U.S. Embassy in Ottawa and Dr. Robert E. Stewart, Director of Prosthetic and Sensory Aids Service of the U.S. Veterans Administration in Washington.

George Klein attended the ceremony and demonstrated the chair for the media and the dignitaries that included J.A.L. Robichaud, a senior manager in another government department who was himself wheelchair-bound.

Newspaper accounts of the event, marveled at the chair's performance and the ease of its control system, but also suggested that the Klein technology was proven and even well known in some circles: "the Klein Chair – as it has become known – is manipulated by the slightest finger pressure. It can go in any direction the drive wishes and is so mobile it can be driven through a space of its own width".[323]

There was no doubt about the intention of the event. "Because the demand in this country isn't large enough to manufacture large numbers of the chairs, the presentation of one of the units was made to the United States in hope a large enough demand will be made to interest a commercial manufacturer", the *Ottawa Citizen* said at the time.[324]

Almost five years had passed since Major Bell first came to NRC for assistance, and two years had gone by since the working "model" had been completed in 1953. Parts had been purchased for the 20 chairs envisioned by Veterans Affairs, and nine had been built. Only fifteen veterans had been identified as needing the chairs at this point. No estimates of the non-veteran civilians needing them had been made, but there was a high degree of confidence that a substantive market existed in the U.S. and other countries where people were relying on what was called "the old-type units".

As promised, the U.S. Veterans Administration did subsequently share information on the Canadian wheelchair with "all known" wheelchair manufacturers in the U.S. Three firms responded formally with interest in building chairs based on the Canadian technology, and one was identified as already capable of making motorized chairs: the American Wheelchair Company in Indiana,[325] which had been making chairs based on the old 12-volt system that Klein sought to replace.[326]

In 1956, just two years after witnessing the "Klein chair" in action and acquiring Klein's report, Everest and Jennings launched its own model of what is now cited as the first "commercially available" power drive wheelchair in the world.[327] Later when Canadian government officials were asked to recommend commercial sources of powered wheelchairs, they would cite the E&J version as the one with a drive system most "similar" to the original "Klein chair".[328]

Before the end of the 1960s, E&J was to have sold over a million of its powered and manual wheelchairs and expanded to include manufacturing operations in Canada.[329]

Eventually, other, larger medical device manufacturing interests absorbed the firm, and Canadian operations were scaled back.

But it is interesting to consider the ultimate impact of the Canadian decision to freely share the technology and a unique invention, not only with the disadvantaged users, but also the international manufacturing interests that would market and profit from it. It may well have fostered more economic benefit and employment in Canada through indirect means than a well-intentioned, but ill-advised attempt to hold onto the secrets and hope that a Canadian manufacturing concern might materialize.

A New Kind of Collaborative Research is Born

By February 1962, over a decade after Klein first started working on "the wheelchair project", the Department of Veterans Affairs was able to look back and assess the initiative from the perspective of its mandate and its narrow objective to provide devices to the most severely disabled of its own clients.

The original modest projections of up to 20 such individual veterans in Canada seems to have been fairly accurate despite any impact of the Korean War. Seventeen (17) chairs, including the prototype and the one given to the U.S. were built in all by the Department for its own purposes. Ten (10) were used in Toronto alone because of the rehabilitation centres there, but the others were distributed from Halifax to Vancouver.[330]

This report echoes other sources in both reaffirming that the Klein Chairs performed well with no maintenance problems. But, more interestingly, the report also documented ongoing efforts to improve and advance the technologies driven by patients. More than passive recipients of completed works, the disabled veterans not only manifested the demand: they guided their creation and ensured their utility through their perseverance and innovation.

At Camp Hill Hospital in Halifax, a patient (Mr. Borden) helped hospital staff with a design change that greatly increased the potential use for the Klein Chair. Klein's original design with its manual control switches on the armrest assumed that users would have at least some minimal ability to move one hand. But Borden had to wear support braces just to keep his wrists in place and thus could not even push the switches with his arm. He and the hospital staff worked out a way to place the control in front of his body where he had greater leverage allowing him to gain "a great deal of satisfaction and pleasure from the chair (which he was then) able to manipulate quite successfully".[331]

The most inspiring innovation in the report involved "a quadriplegic victim of Poliomyelitis (whose) Residual movement (was) confined to his head and neck". For the most part, the man could rotate his head in both a horizontal and vertical plane, but even these movements on his left-hand side were restricted. His difficulties were magnified by the fact that the "disease (had) also affected the chest musculature to the extent that he (had to) move his head continuously to breathe".

At first, the chances of him using a Klein Chair seem impossible. His case could have easily been considered beyond the reach of even the then transistor age of technology. In fact, without the patient's own drive, determination, and dream, it is certain that no attempt would ever have been made to develop a revised Klein chair. But this human, normally confined to a horizontal rocker bed, "was very strongly motivated" and wanted to do anything to "obtain some degree of independent movement".

His will inspired others to adapt a Klein Chair with an even more impressive alteration of the control systems. The "switch (was) mounted on a swivel bracket so that it (could) be adjusted against the patient's cheek" then when he was not using it, the control mounts allowed him to swing it out of the way, again using his face. It took days and days of practice for him to make it work. He not only had to use his face to push the controls, he had to maneuver it around just to see what he was doing.

Weeks passed, but he persisted. Finally, well over a month after the device had been rigged up, he not only managed to make the controls work as he wanted, he demonstrated to the hospital staff that he could be left to travel on his own and no longer required an "escort for his many trips".[332]

This was the kind of human spirit George Klein encountered as well when he first worked with patients and offered the hope of real mobility and independence. They were his collaborators and partners. In discussing his project with reporters, Klein admitted that he had had other "other interesting projects", most of which were still on the "classified list", but that he had obtained a larger degree of satisfaction in designing the wheelchair.

"It has given me a feeling of helping others, who have always been unable to help themselves", he said.[333]

It is now well accepted in the field known as Rehabilitation Engineering that a very special combination of scientific, technical, and personal skills is required and that the patient is at the very centre of the process. It is work that can involve electric circuits, machine design, and mechanics as well as a scientific approach that both acknowledges the human nature of the work and maintains the rigors of systematic testing and standards.

But it was all new territory for scientists and engineers when Klein and his colleagues attacked their special challenge over half a century ago. In fact, Klein in many ways broke new ground and helped define the field.

Years later, Klein's work continues to stand up, even in the midst of many subsequent developments, as a major turning point in the engineering profession. Although Klein was not "the first to invent an electric powered wheelchair, and his report states as much", his invention and "design did make some important contributions (and) is quite possibly the first practical electric powered wheelchair in terms of performance, costs, and reliability". His project made several important contributions to the technology. In addition to innovations such as the dual electric motors, the 24-volt system, and the smoothing control systems, Klein's work, as a by-product, introduced pioneering approaches to performance testing and laid the foundation for standards for wheelchairs.[334]

Klein and others "created devices that later went on directly into commercial manufacture or greatly influence commercial products".[335] But even more significantly, he was a member of the first generation of engineers who took their skills and knowledge of aviation, mechanics, and other fields and brought them to the service of people with disabilities.

Klein's wheelchair project and innovation played an important part in the broader international drive to help WWII veterans and, in doing so, changed the nature of research, engineering, and innovation. By pursuing further developments in wheelchairs, prosthetics, and other devices, they created a new profession and application for mechanics, electrical engineering, and design.

"In fact, it is likely the formal beginning of rehabilitation engineering".[336]

Klein benefited from a lot of help in the project including support from his Director Parkin and collegues in the Engineering Lab some of whom came to the Klein group in September 1953 from the aeronautical laboratories. Klein explicitly recognized the help he received from the aviation side of his Division in the wheelchair work. Klein's own background and associates in aeronautical research may have contributed to his improvement in the "joy stick" controls on the wheelchair as well as his recognition of the option of using powerful aircraft motors on it.

Yet Klein and his engineering contemporaries would have been quick to acknowledge that the most important players in their achievement were the doctors, medical staff, and, again, heroic disabled veterans. In fact, Klein concludes his technical report with a statement of thanks to officials at the Department of Veterans Affairs for presenting him with this challenge because it brought him in contact with the inspiring staff and quadriplegic veterans in Toronto hospitals.

The paralysed veterans probably were not even aware of the extent to which they themselves defined the rate of innovation and technology development. Perhaps, because the spinal chord injured veterans of WWII were otherwise healthy, young, and proud, they were more inclined, than older disabled civilians, to demand more, experiment, confront the stares, and "set the pace". They "ventured out in wheelchairs in all kinds of weather ... they pioneered successful living and working in the community. By their example, they taught the public that there was life energy and purpose in human beings even when seriously physically impaired". [337]

They also brought patients, physicians,[338] scientists, engineers, and government officials together in common purpose and innovative partnerships.

In this respect, Klein's greatest contribution through his wheelchair project was not as the inventor of a specific device, but as a humble part in the creation of a new venue for human beings of many strengths, skills, and interests to come together to collaborate, advance knowledge, and innovate.

"the drawings were not materially delayed by introducing several improvements in design".[339]

The War History of
the Division of Mechanical Engineering
National Research Council of Canada

8. A THOUSAND ODDS AND ENDS, AND A FEW BAD IDEAS

He had a problem. The researcher knew a lot about the science of ice and snow and the importance of his field of study. Picking up where George Klein had left off, the scientist had, in fact, helped to improve and refine Klein's snow classification and data-gathering techniques throughout the 1950s. But he could not match Klein's talent for mechanical design and invention. Klein's willingness to help, to make do with what was practical and available, and to see his inventions embedded in the work of others was well known.[340]

NRC snow researcher Lorne Gold, thus, naturally turned to Klein for many years after the two had first met in 1950 for ideas on how to expand snow research and introduce new measurement techniques into the system.

He walked down the hall and through Klein's open door. Gold said he needed an entirely new device: one that would impact on snow horizontally at high speed to basically give the snow a hard punch in order to measure yet another feature of the strength and consistency of snow.

As the two men talked about the problem in the cluttered NRC office, Klein thought about what such a device might look like. Almost instantly, an image came to his mind that reminded him of the starter motor for aircraft engines. At the time, starter motors were cranked up and then released sending a fairly consistent blow of energy to engage an aircraft engine. The shops at Klein's lab had some starter motors lying around, and it was easy to configure a device using one of these spare ones to try out the idea. It worked, and Gold used it as yet another contribution to the world of snow-measuring equipment. This was not a device that would be considered for patenting, development, or even significant production. But it met the need of the moment, and like many of Klein's innovations, only took a bit of his time and only survived as a fond memory with the direct beneficiary.

As years pass and slowly take away those who benefited directly from his generosity with time and talent, it will become increasingly difficult to ever catalogue all of Klein's inventions or innovations in design. Only a hint of the full inventory exists among the cryptic comments within technical reports and monographs.

As the authorized history of Klein's Division of Mechanical Engineering points out, his work was pervasive and yet nearly invisible. Only when he undertook sustained, long term, personal projects did he consider it worth reporting in a way that would see his name associated officially with the work in the records. In one six-year period, for example, Klein's entire section only rated two separate mentions in the Division's Quarterly Report: one on his aircraft ski work and one on his snow research. But during this time, Klein's group was incredibly busy, productive, and inventive.

At times, it was said that "problems were heaped upon the (Klein) Section" from many directions, and yet even the "intractable" problems were solved thanks to "the great energy and almost unbelievable ingenuity of George Klein". He was considered a "cornucopia of mechanical ideas".[341]

Sometimes, Klein's work was kept secret on purpose. When he was working on military issues during the war, the benefits of secrecy were obvious, and the need for formal or broader communication of invention was less important when the military client would take a design or device and put it directly into controlled production.

Another reason his numerous inventions often missed formal recognition flowed from his role as the inventor and designer of one-of-a-kind devices for others to use in their research. The Division History mentions almost in passing that "Klein was involved in many of the investigations that have already been described" in previous chapters about the achievements of other people. Klein's "major activity" was "the design and development of equipment for various other laboratories".[342]

While this kind of supporting role kept many of his inventions hidden, it did put him in contact with a lot of creative people and in the vortex of a whirlwind of problems and ideas. In time, many of these people would offset the omission of the sterile official records with lively firsthand accounts of experiences working with George.

Such stories make for vaporous evidence, but they are compelling in quantity.

A decade after his death, it would still be near impossible to find anyone who knew Klein even briefly in a work setting, who did not have a favourite "George story": a story that not only speaks of special cleverness and a unique mind, but also of volume and the commonplace, routine regard with which he viewed his own invention and design work.

He was, after all, just doing his job.

George Klein came to work each day with a responsibility to find new and useful ways of doing things. He developed new processes and new machines, and he found ways of improving existing devices. He was the cornerstone of a cornerstone group within the growing and active research organization. The skilled craftsman in the shops and client factories would most often work with specifications others had prescribed, and the research scientists would be pursuing more fundamental issues. Klein and his team had to bridge the two worlds with the original design of tools and instruments that made the research possible. As his reputation for usefulness spread, people within NRC and outside would seek him out directly to create something new, and, more often than not, Parkin and other managers would routinely, almost without thinking, direct that a difficult, new technical problem "be given to Klein".

The problems were, almost always, mechanical, and, almost always, like research on snow, treads, and skis, very Canadian.

A New Dog Sled for the Mounties

It would be hard to find a more Canadian, more illustrative story than "the Klein Komatik".

By the late 1940s, Klein had already developed an affinity for life in the North. His early work on aircraft skis had taken him to remote northern locations, and some experiments on barge design in his marine testing basin were fuelled by development and exploration of the Arctic. Discoveries such as the one that led to Gilbert Labine's pitchblende mine on Great Bear Lake and the links to remote communities built by the bush pilots contributed to a greater fascination with the north.

Modern interest in Canada's northern development has its roots in the late 19th Century and the Klondike Gold Rush in the Yukon Territory.

Adventuresome and daring, those who defied the cold, the wind, and the scarcities of the north were not always the kind of people who could be relied upon to obey the law and respect the rights of others without strong encouragement. They were lucky, although few would have admitted it at the time, that they had such strong encouragement in the form of the North West Mounted Police (NWMP), the forerunner of Canada's famed Royal Canadian Mounted Police, the RCMP.

Even before the big rush was on, rumours of gold discoveries prompted the NWMP to send in a small detachment of about ten men to the Yukon. It would grow tenfold within a few years. They saved many lives by keeping the peace and enforcing safety regulations making the Klondike gold rush "the most orderly in history".[343]

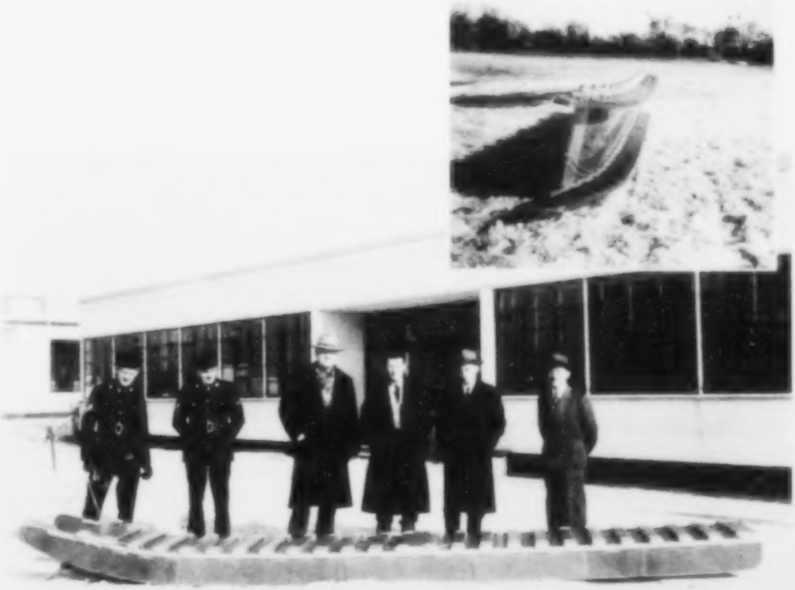
Using the St. Roch schooner, the vessel that was first to circumnavigate North America, as a mobile base among the Arctic islands in the 1930s and 1940s, the RCMP became a special presence and symbol in the North. Consequently, despite other pressures, Klein welcomed the opportunity to serve the Mounties when, in 1947, they came to his laboratory seeking help. They wanted him to design a better Komatik, the heavy version of the Inuit dog sled, for police use in the far north.

The Mounties were expanding their patrols in the eastern Arctic, and they were hoping Klein could make the job easier by designing a lighter and faster sled. At the very least, they thought he might be able to come up with a design that would erase the need to constantly "re-ice" or cover the runners with ice. Ice on the runners helped the sled slide better, but applying the water or melted snow was not always a pleasant task in mid-winter. It was, once again, a "different thing" for Klein to tackle.

As usual, his response was to start with a model.

But this time, he was not dealing with an aircraft, a train, or ship: his model could be full-sized: the traditional "18 feet long and 30 inches wide". Throughout the fall of 1947, Klein and his team conducted tests and studies on a construction design that the Inuit had evolved over the centuries. He was, of course, thorough, open-minded, and persistent.

Yet he would conclude by the end of the winter that the Inuit's overall design "could not be improved upon".[344] Clearly through a survival of the fittest process extending over hundreds, possibly thousands of years, the Inuit instinctively moved toward the most appropriate structural and aerodynamic design for their needs. Klein was pleased to advise the RCMP of his findings, and it was seen in part as a vindication of the ingenuity of native peoples.[345] His main goal was to help the Mounties, not to re-invent the Northern wheel.



George Klein (right), members of the RCMP, and colleagues with proto-type of the Mountie's new sled *(NRC Archives)*.

Klein's only helpful new ideas were those drawn from his experiences with aircraft skis and his awareness of new materials. He covered the runners with laminated bakelite, the synthetic plastic-like resin that he used so often in his ski research, and he used nylon parachute chord to lash the cross bars, which were a core feature of the Inuit design, onto the runners.

His one other novel, functional "improvement" was the addition of a thin sheet of Bakelite material in the form of a kind of toboggan bottom under the cross bars and above the runners. This special sheet shielded the cross bars and made them less prone to catching on rough ice, rocks, or small bushes. Klein's Komatik dog sleds worked and were used for a number of years by the Mounties into the 1950s even as the personal snowmobile and a new era in bush flying created other options.

Nevertheless, despite this success, the invention could only be described as better from a limited perspective.

In the remote North, advanced materials such as nylon and plastic would lose their attraction quickly when one had to consider the eventual need for replacement parts. A vehicle that can be repaired with scrap wood and rawhide thongs is much more appealing in most Arctic circumstances.

And while Klein's Bakelite shield may have been a welcomed innovation to Mounties rushing to the scene of a crime, it would not have had much of a market among Inuit hunters. Fortunately, the Inuit were not compelled to use the new Komatik from Ottawa since the Bakelite vibrated in use. It produced a persistent pounding noise.

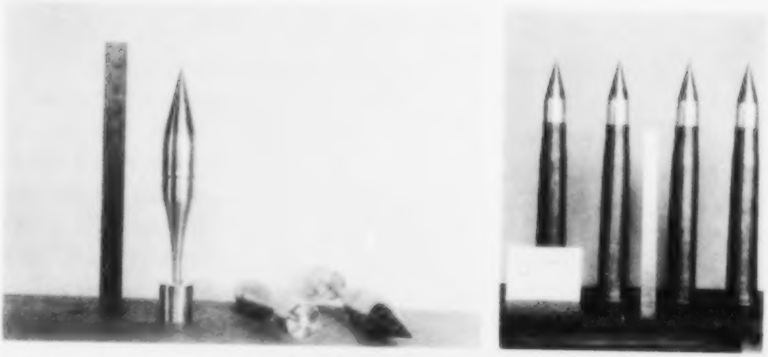
The Klein sled sounded like a loud warning signal and scared off game. One could starve to death in the Arctic using an invention like that.

The General's Gun Bore Idea

There were few, if any, other Klein inventions that could be considered life threatening to the potential users. There were a couple, however, that had the air of a bad idea even though his work was solid. One such project was hard to avoid because the assignment came from the top.

Over the course of the war, Klein became an expert in the functioning and design of projectiles and fuses. His involvement in the field began with a special request from the NRC President, not Acting President C.J. Mackenzie, but the on-paper President, Major General Andrew McNaughton. McNaughton, who was on leave from NRC for war duties in Britain, had come to believe that anti-aircraft guns could increase their accuracy significantly if the bore of the gun barrels could be tapered correctly. The Germans had reportedly experimented with this design in the 1930s, and McNaughton shared the widely held, aching desire to increase the precision of Allied anti-aircraft fire. The challenge and the General's idea were conveyed to Mackenzie, on to Parkin, and then to Klein.

McNaughton knew Klein and his work. Klein's name would come up often in the wartime reports sent to the General by Mackenzie. Mackenzie's letters to McNaughton, in fact, include many terse references that add to the inventory of little Klein inventions: "Klein has developed an improved slide rule for range calculating, and will be sending you three samples shortly".[346] "I have brought together in informal



Klein developed many different kinds of armaments during WWII *(NRC Archives).*

association … and Mr. Klein … to serve as special investigators and designers for problems suggested by (the military)".[347] "Klein and his group are working full time on design and the shop is actually producing predictors, gun sights, etc. for coast defences".[348] "We are keeping all the pressure we can on him (Klein) and his group".[349]

Despite the wide variety of Klein-led projects, the General was clearly most interested in his work on the gun bore idea, and through correspondence with Mackenzie, McNaughton's interest, new ideas, and suggestions had a direct line to Klein and his lab.

Klein had "grave doubts" over the General's gun bore theories and was very concerned about the lack of any prior supporting data or experience; still, he accepted the task and attacked it with his customary diligence.[350]

Many hours and many miles were consumed in the early days of the War as Klein tried out different projectile designs as well as different measurement techniques in the labs and on firing ranges. He developed his own systems to track muzzle velocity even building his own high-speed photography system to record these experiments. He made many odd shaped bullet covers, bullets of various alloys, and, of course, weird bore designs. Some promising approaches turned out to be impractical because they could not accommodate a big enough explosives package. In the end, the evidence Klein assembled would demonstrate that even the most sophisticated bullets and the most efficient bore designs could not outperform another technique: simply lengthening the bore of the gun and using standard bullets.[351]

The Watchmaker's Son Invents a Timing Device

Klein's work from McNaughton on projectiles would be recorded as one of the "ill-advised" technology projects of the War. But through the experience, Klein became an expert on what did and, evidently, what did not work in the design of guns. He was far from the only ballistics or armaments expert in Canada or even at NRC during the war. But his expertise would earn him a seat at the table designing many devices, and his knowledge was useful in enough other projects to make "Armaments" one of the identifying responsibilities of his small research group.

It would also lead him to an invention that was brilliant in its simplicity and effectiveness, popular with those who wanted it, and, in a small way, responsible for saving many lives and influencing the course of World War II. It was a contribution to what would be one of the War's "wonder weapons": the proximity fuse.

Few research projects could match the importance and grandeur of the international effort to develop a "proximity fuse", just one of several names given to any gadget that caused shells to detonate in close proximity to a target rather than requiring actual direct contact.

It began as a British-led project fuelled by the stress and threat manifested in the Battle of Britain. At the outbreak of the war, the defenders might have been better off throwing handfuls of sand at approaching bombers than using the existing anti-aircraft mortar shells, which had a one-in-4, 000 chance of hitting their target.[352]

The British soon engaged the help of the U.S. scientists and military, sharing their expertise with the understanding that U.S. industry, in turn, would help supply Britain's wartime needs. Canadians became involved through the high level contacts of the Acting NRC President. Mackenzie was always conscious of the post-war scientific and industrial potential in the new military inventions.[353] As the proximity fuse technologies were refined and focused upon the version based upon radio signals, the enormous American effort began to take the lead and the control.[354] Britain, dependent upon the finished product, would eventually lose almost all authority on both the design of the fuse and the allocation of proximity fuse production. Canada too would have minimal influence on the strategic military and industrial decisions around the device.

What influence and benefit Canada did witness was a function of an exceptionally effective NRC-funded project at the University of

Toronto.[355] Led by Arnold Pitt, the Toronto team developed an ingenious battery that remained inactive until its electrolyte materials were freed from their glass container. Used in the proximity fuse, the battery could remain in storage without risk of dying, but would jump into service once its glass case was broken by the force and vibration produced in its accompanying shell after firing.

NRC's involvement and the credibility of Pitt's work led the international team to think of Canada when confronted with another proximity fuse problem: one of particular concern to some U.S. military planners. They wanted to make sure that the shells, armed to sense close proximity with a solid target, would not mistake the gun barrel or ambient dust as the hunted object. A timing device was needed to give the shell a set period to clear the firing area.

The problem had stymied the U.S. team, which may have been blinded by a bias toward its own timing device technologies. Their timing devices would often prevent the fuse and shell from firing at all. A solution would, obviously, have to be novel and creative. But because the Allies needed thousands of fuses, mass-produced within a short time, the solution would also need to be simple, easily repeatable, and inexpensive. When the NRC managers and Canadian military experts were presented with the challenge, they naturally turned to Klein.

Klein questioned the need for such a device almost from the beginning. He had had some experience with armaments and explosives, and just as he would later conclude studying the Inuit Komatik, Klein felt that there may not be any real need for an innovation since the process of freeing electrolytes and initiating the electrochemical reactions would involve the requisite delay time anyway. But the request came from Pitt himself and, Klein was told, "the Generals wanted it". They needed more comfort because full-scale production would be costly in many ways and would divert industrial resources from other work.

Their comfort level would be raised if the fuse had a dependable timing device. Aside from the military brass, there were others involved in the fuse development who were merely supportive of any innovations that might improve the device or, at least, wanted to remain open to innovative input from any direction and from any country — even Canada.

As usual, Klein delivered the technological goods. He designed and built a simple and effective timing device that worked well when tested and performed as needed.

Using his knowledge of what happens to a shell moving through a barrel, Klein realized that the centrifugal forces would be predictable and would provide a consistency that could be the basis for designing a timing device. He would also call upon another special source of knowledge: his father's Hamilton watch factory.

Klein's proximity fuse timing device thus was based upon the dependable effect of the centrifugal forces combined with coiled up springs similar to clockwork. The word "clockwork" not only implies springs and gears, but precision engineering, and the Klein proximity fuse timer was both. Yet it was also simple, and as requested, simple to make.

Its mechanism was kept together by the straightforward force of inertia until shaken into action.

The Canadian, U.S., and British military clients were impressed, and a large number of proximity fuses with the Klein innovation embedded into them were produced for demonstration purposes. They were given to the military for absorption into the larger effort to refine and improve the overall proximity fuse system. It must have been hard for Klein to cheer as he still wondered if he was helping or not since he was always looking to keep systems simple and uncluttered. His invention seemed like a frill.

Eventually, Klein's suspicions about the need for such timing devices were confirmed in future generations of the proximity fuse. Still, even if the directive to design such a device may have been a borderline bad idea, Klein was clearly and efficiently helpful in increasing confidence in the design and assisting in its development. Through this project, he played a constructive role in bringing the proximity fuse to fruition and to maintaining Canadian interests and credibility in a device that would implicate and drive key industries ("one-quarter of the total U.S. electronics, and three-quarters of the U.S. plastics moulding"[356] facilities were involved in proximity fuse production before the War's end). These industries were defining forces in the post-war economies. Even this modest Klein innovation had a small impact in a much larger enterprise.

At the time, the most important concern was the fuse's role as a genuine benefit in the Pacific combat against kamikaze planes and in the defence of Britain during the desperate, last ditch Nazi "buzz bomb" attacks in 1944.[357] A clumsy forerunner of the Cruise missile, Hitler's buzz bomb rockets were an unnerving and deadly aspect of the last year of the War. Fortunately, the well trained defenders on the ground and in the ai were supported by the new proximity fuses, which played a major role in increasing the accuracy of antiaircraft fire ten-fold.

For Klein, it was more than just another intriguing, but surmountable technical challenge. He had colleagues and friends in Britain in 1944, and he was proud to have had a chance to do his best in their defence.

The Mechanics of Radar

The cliché that "success has many fathers" seems to have a special resonance in science and technology, an arena that somehow sees all of the players standing on the shoulders of others. It is certainly true of the proximity fuse, which involved many innovations and groups, and Klein probably qualifies more as a mid-wife than a parent. Still, he was one that was clearly innovative and useful when called upon.

The metaphors are even more apt, however, with respect to the story of Radar. The development of Radar for WWII, even more than the dramatic nuclear physics that punctuated this segment of history, stands as the archtype of technological innovation of broad benefit, driven by military intent. Canadians were energetic, effective, and exceptionally significant players in both magnitude and novelty. Yet they were far from being the "inventors of Radar" which involved many people in many nations.

One of the few catchy acronyms to flow from modern science, Radar or Radio Direction and Ranging devices are at one level very simple systems that measure the time it takes to reflect electromagnetic waves off a distant object to derive distance and direction. But the conversion of this simple principle, which had origins in the 1880 works of Henrich Hertz, into machinery that can work consistently to track fast moving objects at long range in a wide variety of unforgiving circumstances draws upon a variety of technologies, expertise, and materials.

Canada's strongest claim to parentage would likely rest on the 1925 invention of two military men, a future NRC research manager, W.A. Steel, and the future NRC President, Andrew McNaughton. Together they conceived of a method of navigation using radio waves and the basic Radar principles of triangulation, measuring the time involved in bouncing waves off two known points in order to map another. The waves were expressed upon a cathode ray tube, much like a TV set, and their invention, a type of navigational Radar, was called the Cathode Ray Direction Finder and patented.

A little over a decade later, as NRC President, McNaughton and his partner would give their patent away for a dollar to NRC. With McNaughton's sense of looming war, this technology and prior patent, which was recognized by British scientists in their 1930s Radar work, would give NRC and Canada the basis for original work and a frail, but evident technological base to build upon.

In the late 1930s and first years of the War, the British scientists had established a lead in Radar development and ringed the Southern end of their island with facilities that would underpin their airforce's surprisingly effective response to the Luftwaffe in the Battle of Britain. The Brits were ready to take a major leap forward when their scientists developed the cavity magnetron, a device that produces high frequencies with great power, just the combination needed to dramatically increase the effectiveness of Radar. Specifically, the new magnetron would make microwave, 10 cm wavelength, Radar systems possible.

Under the pressure of possible invasion, the British did what they might never consider in the context of peacetime commercial competition. They gave their invention away. The Tizard Mission, a phrase recognized by science war historians as a turning point for North American technology, was the label given to a delegation led by Sir Henry Tizard that traveled to the U.S. and Canada early in the War to seek help in the further development of key technologies and, if dictated, production for the armed forces.[358] The proximity fuse was one subject of discussion; the seed of what would become nuclear research was another; but the most significant was Radar and the secrets of the cavity magnetron.

Canadians, thanks to McNaughton's vision and the skills of a few physicists such as NRC's J.T. Henderson, seized upon the opportunity, and, for a period, would mark some significant achievements over the U.S. teams.[359] Canadians through the NRC were the first to place a Radar installation into operation in North America with a coastal defence system near Halifax (the Night Watchman – so named partly because it lacked alarms or recording systems and thus required manning by an alert watchman). The NRC and its associated crown company Research Entreprises Limited (REL) became, in fact, the first organization to mass produce a successful 10 cm Radar system using the advanced magnetron. This was an anti-aircraft gun laying system known as the GL Mark III-C, the name given to the Canadian developed version of the system.

The Canadian system drew primarily upon the brains of electrical engineers and physicists at NRC, but it was also a mobile truck-like machine, which also required new types of gearing and mechanical systems. This machinery not only had to be efficient for a specific use, but also sensitive to the novel electrical and radio equipment it carried.

Inevitably, Klein was called upon to help with these mechanical design issues.

His specific contribution would be the design of a new type of "bearing transmitter gear train", the mechanical machinery that supported and facilitated the rotation of the radio antennae. Thinking specifically of anti-aircraft uses, the NRC physicists and REL engineers wanted a mechanical gearing system that would have no problems with backlash and could be easily adjusted to a number of different aircraft prediction systems then in the field.

The Klein gear train not only met the needs, it was notably "compact, readily accessible, required very little maintenance, and was well suited to mass production".[360]

It was mass-produced by REL. They sold Radar units in the thousands, earning the equivalent of billions of dollars in year 2000 values by wars end. More importantly in the long term, the Canadian Radar program trained hundreds and hundreds of electronics engineers and technicians establishing the human and national technological infrastructure for many of the country's innovative industries after the war.

Almost inescapably, Canadians lost Radar business to the overall technological edge that came with the enormous U.S. Radar development and industrial production program.[361]

But, again, an innovative collaboration of Canadians that included George Klein had first laid down a marker to ensure that their country would have a seat at the table for the electronics and high tech era that followed in the decades after the War.

The proximity fuse and Radar development projects during the War were certainly not George Klein initiatives. His involvement as a foot soldier is not a testimonial to a great lone inventor, but rather an illustration of the ubiquitous nature of his work and service.

It is, of course, a quality of mechanical engineering and design to reach into many fields of science and technology. Perhaps, it should have been expected that the most intriguing and important tasks of the day would find a way to embrace the most talented, connected design engineer in the national service. There would be other wartime projects, of course. Many more.

Anti-Submarine Warfare in an Ottawa Aeronautical Lab

Most would come to Klein via the military or indirectly from his colleagues in the NRC mechanical and aeronautical research labs, who themselves were working for the military.

His creative fires were stoked from two directions: the pull of unusual problems and the support of experts in other fields. Klein often remarked how he was lucky to be working in a place where he could find, within walking distance, world experts in acoustics, electrical engineering, and biology as well as mechanical, construction, and aeronautical engineering.

One celebrated example of both forces at work on Klein resulted in the invention of the Automatic Stabilizer for the Hedgehog.

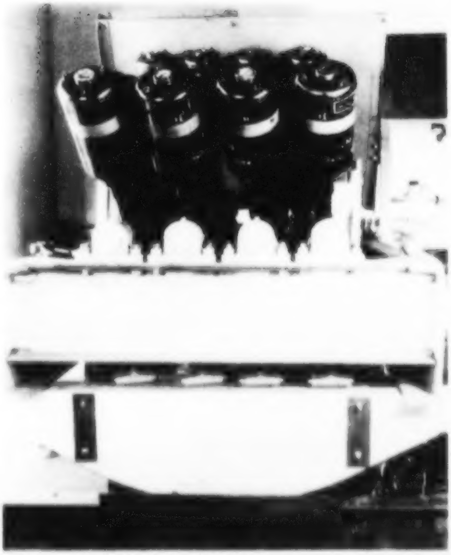
The Hedgehog, named for the animal whose defence system is a forest of hard quill-like spines, was a World War II anti-submarine weapon that featured a forest of small depth charges. The Hedgehog consisted of a platform that sat at the back of naval vessels and that could eject the depth charges in a pattern that maximized the chances of hitting a submerged enemy submarine.

Crews on the ship had to fire the depth charges manually and could only do so effectively if the Hedgehog's platform was kept consistently level. Gyroscopes, instruments that worked along with the horizon as a guide, were integral to making references and then keeping the platform level in rolling seas. The subsequent firing of depth charges was done manually by crews sliding and running across open decks.

Even as the War progressed and Allied convoys were able to cover more of the Atlantic, the Royal Canadian Navy (RCN) played an important role in escorting ships over the last few hundred miles into North America. But the Hedgehogs had been developed for the British navy, and, as was often the case, the British sources were cut off or less inclined to supply North American needs. In 1944, the RCN came to the NRC laboratories for help because they could no longer get gyroscopes from Britain.

They got more help than they anticipated.

Klein looked at the problem and suggested that the Canadians could do better than merely copying and making replacement parts. He suggested that the Navy might try using the same kind of stabilizing system as aircraft makers: the so-called gyro-pilot which did not depend upon sighting the



A test model of the Hedgehog anti-submarine system in the NRC labs *(NRC Archives)*.

horizon or on the same human intervention. The gyro-pilot was a technology outside of Klein's realm of expertise, but not his organization.

S.J. Murphy's group in the aeronautical labs understood the system well, and even more importantly, they quickly understood Klein's concept of applying it to the Hedgehog. Together they rigged a platform in the NRC lab and simulated the rocking motion of a ship at sea to test out the system.[362] Eventually, through trial, error, and some predictable set backs the researchers came up with a device that not only replaced the function of the scarce gyroscopes, but also acted to stablize the platform automatically. They could not have done it without each other, and, in fact, they could not have done it without the NRC instrumentation shops that eventually manufactured the prototype automatic stabilizer. The device was built, tested at sea, and put into production by the Navy. It even performed flawlessly in heavy seas and storms that would have made manual operation of the Hedgehog depth charges impossible.

It was not merely a package of instruments and inventions, but also of other design features that fought corrosion and protected the system from the shock of naval warfare. The Canadian navy put it into production, and the tide had shifted. The British Admiralty was now separated by an ocean from superior technology.

Inventions of the Mind

The Hedgehogs with their stabilizers were large, heavy, and obvious inventions drawing upon laboratory and shop facilities as well as teams of engineers and scientists. Other Klein inventions drew upon much more modest and simple resources: Klein's imagination.

Klein had a special capacity to visualize mechanical systems and blend the images with mathematical formulae into techniques that others could apply.

This talent helped in many situations including one that manifested, like the Hedgehog, as a result of wartime shortages, the wolf pack U-boats, and pre-war dependency on foreign-made technical products.

Before the war, Canada depended upon the Woolwich armory in England for supplies of artillery sighting parts. This supply was cut off just as the defence of Canada's east coast became more important than ever before.

Artillery use along the coast has special features. Because the weapons are fixed in a known position and because the targets are always at a predictable height (sea level), the potential exists for designing sighting devices that can also simultaneously predict the distance and location of the target. Such sighting devices are operated with the help of a "cam", a small attachment used for making precise adjustments in the process of sighting a target. These cams are designed and made in a way that considers the location and sea level variations of the specific gun being used.

These facts were well known when Klein was asked to help design replacement cams for Canadian coast artillery systems. But as he worked on the designs and thought through the process, a consistent pattern emerged in his mind that led him to evolve a new, simple technique for determining the shape a specific cam should be. The NRC shops, in turn, devised an equally innovative process for applying Klein's design formula, and the Canadian artillery cams were produced with greater efficiency, elegance, and effectiveness than anyone expected.

Over one hundred devices were designed and produced drawing upon the new technique. It was not one of the great production runs in military industrial history, but was another example of new ideas and innovations that were clearly useful to Canada.

Blood and Mechanical Engineering

When the war ended, the military pressures on Klein and his group declined, but in a way, the true source of demand for his expertise never abated. This was Canadian society.

The wheelchair project and Klein's brush with the founding of rehabilitation engineering was, of course, an expression of the influx of returning veterans, but it was also a symptom of Canada's increasing interest in health care and medical research which had been fostered by individuals such as Sir Frederick Banting and neurosurgeon Wilder Penfield. This interest would lead to the NRC's creation, in the 1960s, of the separate Medical Research Council of Canada (MRC), a body that would evolve into the Canadian Institutes of Health Research (CIHR) before the end of the century.

In the early 1950s, cross-pollination between medical research and other disciplines took root when heart surgeons, Bigelow and Calahan, teamed with a young NRC electrical engineer, John Hopps, to invent, develop, and build the world's first heart pacemaker as an external-to-the-body device that inspired the implanted pacemakers that followed. Through Hopps, who built upon his heart pacemaker experience with other innovations for the disabled, the profession of biological and medical engineering was founded in Canada and, in part, internationally.

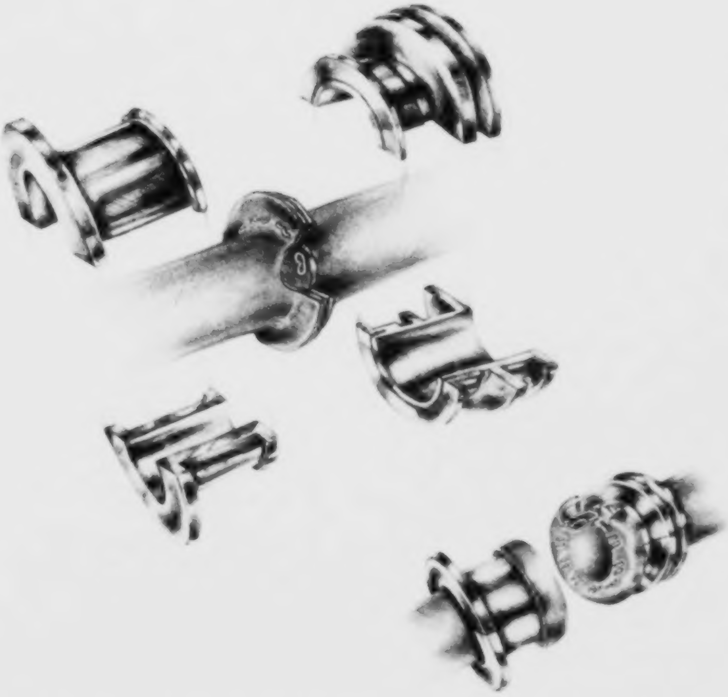
Hopps was not the first NRC engineer to work with medical researchers. Parkin's lab was approached by an Ottawa physician for help in designing what became a practical innovation to blood transfusion equipment in the 1930s, and, of course, Hopps was not the last.

In the late 1950s and early 1960s, the field of medical research would lead George Klein to develop an invention that his Director Parkin would see as the "incredible" one, a rapid, mechanical, blood vessel suturing instrument.[363]

Even 40 years later, the device is an intriguing gadget that looks like it stepped out of an invention hall of fame as the arch-type of utility and cleverness. As with Hopps' pacemaker, the invention would never have been conceived or, more certainly, successfully developed without the cooperation and enthusiasm of the desperate surgeons, who were frustrated and discouraged by the painstakingly slow and intricate process of suturing blood vessels.

When a vein or artery is severed, a patient literally risks losing "life and limb" unless the blood flow can be restored quickly. Almost instantly the ends of the vessel turn away. The process of connecting them prior to the development of specialized equipment called for a rare level of surgical skill and usually amounts of time that did not exist.

Like many obstinate problems, it found its way to Klein.



Klein's suturing invention - "the incredible one"- for reconnecting arteries was faster and more effective than needle and thread and helped early transplant surgery *(Illustration: Mozhgan Kermanshahy courtesy of the Canada Science and Technology Museum).*

While some of his mechanical engineering colleagues had difficulty shifting from machines to the incised bodies of living things, Klein seemed comfortable in the operating room. He focused on the task and on learning what he could. He and his new friends in medicine produced a device that was a combination of forceps, which brought severed vessel ends together, and a cylindrical stapler, which used neutral-to-the-body metal staples and injected its multitude of tiny fasteners with one quick snap.

Early experimental operations on pigs used large instruments, but eventually a variety of sizes including instruments for vessels as small as 2 mm were produced and proved useful. The device was later developed by others at NRC. They not only made it possible to save the lives and limbs of patients injured in accidents, they also allowed the surgeons to conduct early kidney transplants and at least one emergency heart operation that would not have been otherwise possible. It was again a novel, useful and appreciated device.

The device was also patented, and Canadian firms showed some interest in manufacturing it. NRC had already witnessed the very profitable and impressive commercial exploitation of the medical devices that came from its nuclear research program. Spun off like the Medical Research Council, in the decades following the war, Atomic Energy Canada Limited (AECL) helped provide expertise and facilities for the development of the Cobalt Bomb radiation therapy system, one of the century's most effective treatments for cancers.

But even though Klein's blood vessel suturing device would be duplicated in other countries, brought into general use, and improved by many, it was not exploited commercially by NRC or Canadian interests, and NRC had no will to fight patent infringement cases that would only have the effect of impeding the use of a device that could save lives.

A 38-Year-Old Invention has its Day

As he approached his retirement, Klein would not have predicted that many more attestations to his inventiveness would come.

He certainly could not have predicted the invention that came a decade later – five years after he had left the NRC for retirement and almost 40 years after he finished the relevant research.

In the early 1970s, the world was hit by what was, at the time, called "the Arab Oil Crisis".

It started in the fall of 1973. The Arab oil-exporting countries of the Middle East took tighter control of their resources nationalizing the holdings of U.S. and other foreign oil companies and restricting supply to drive up prices. Oil prices quadrupled, and even though Canada was still at the time a net exporter of oil, Canadians felt the price pinch and the global threat.

The Canadian political atmosphere would foster the creation of Petro-Canada as Canada's own national oil company, and in the early 1980s, under a renewed Liberal government led by Pierre Elliot Trudeau, the

National Energy Program was created to increase and control domestic sources of energy.

NRC responded by investing in alternative energy research and development.

Solar power, small hydro facilities, and hydrogen fuel systems were developed by NRC laboratories and by innovative small companies. An entire Division of Energy research was established at NRC led by engineers and scientists often drawn from established NRC laboratories and disciplines.

That NRC should find itself as a leader in the development of wind energy systems during the 1970s and early 1980s is not surprising given its half century experience with wind tunnel research and its unique – within – Canada test facilities for studying the movement of air over fixed and moving structures.

Wind is a potentially inexhaustible energy source, but it is undependable and the process of tapping its inherent energy is more complex that it might appear. New materials, aerodynamic studies, and, of course, structural design smarts can make the difference between viable systems and failure. The NRC researchers were not alone in attacking these issues in the 1970s, but they became, for a period, the clear international leaders in windmills, specifically the design and development of high-speed vertical-axis turbines, the ones that look like giant eggbeaters. Known as the Darrieus system for the French inventor who conceived of the basic concept in the 1930s, its rotor blades take advantage of the lift effect of wind as well as its natural horizontal forces. Vertical-axis turbines can thus move faster and more efficiently than conventional windmills. It uses the same airfoil science that Klein and his colleagues were exploring in the 1920s at the University of Toronto and later at the NRC John Street labs.

When the NRC built the world's largest vertical axis wind turbine, the 110 metre tall, $35 million windmill at Cap-Chat on the Gaspé Peninsula in Quebec as research project Éole in the 1980s, it not only attracted scientific and technical recognition, but extensive media coverage and public interest in Canada and aboard. One response to the public interest was to establish an NRC visitors' centre and alternative energy demonstration facility next to the park that was by then covering the site of the NRC's former John Street labs. Another response was to tell the public about the work of a former NRC scientist named George Johann Klein.

Windmill research had been the subject of the very first project put on Klein's shoulders in 1929 at the University of Toronto wind tunnel after his supervisor, professor, and friend, Parkin, left for Ottawa and the NRC. The project, which had been brought to the university by the academic from Saskatoon, may have appeared unimportant at the time as the more exciting and novel work seemed to lie with the growing aircraft industry.[364] But it was a particularly Canadian project as the Canadian prairies, wide open, windy and flat, offered one of the few places in the world where wind energy made economic and technical sense in the 1920s. The research addressed a prairie problem with funding from the new NRC.

Almost another 10 years passed before Klein found time to wrap up the testing and write a report on the project. The "Laboratory Technical Reports" at NRC were not something one could whip off in a few minutes like a glorified time sheet or memo. It was not an automatic or perfunctory procedure after running tests or studying a problem; the technical reports absorbed scarce and valued resources, editing, publishing, printing and review. The publication of a technical report was a privilege that had to be earned with truly novel and useful information that was not available elsewhere. The contents were reviewed by critical and competing interests that included world experts in the field working in the same environment.

NRC and its individual research Divisions would only publish the reports because they were deemed to be something that could not be found elsewhere and were clearly useful.

George Klein would contribute indirectly to many, many such reports; one of his own works was Report No. PAA-32, issued June 14, 1937. Its title was "The Design of High-speed Windmills Suitable for Driving Electric Generators". It described a windmill that would "begin to charge a 6 volt battery at a wind speed of 7½ to 8 miles per hour", the cut-in speed typical of good wind turbines even in the early 21st century. Klein's windmill design was indeed unique, and his research was proactive for the times, and, as it turned out, other times as well.

In August 1975, the NRC Aerodynamics Lab issued a new report (LTR-LA-183) to respond to the "deluge" from people wanting to know how to home-build a simple, small windmill as part of their own personal reply to the Oil Crisis. The experimental vertical axis windmills made sense as large scale, engineering projects, but were impractical for individuals without specialized expertise. The new NRC Report thus described the most innovative, yet practical design for a small, standard windmill that the world-class experts in the Lab had ever seen. The windmill design set out in the Report was clearly the most sensible option for most ordinary people wanting to capture wind energy for their homes.

The document was a reissue of Klein's 38-year-old report.

Only slightly edited to update a definition and to replot the graphs more clearly, this new version of Klein's 1937 Report on windmills was in heavy demand, and many copies of the reprint were sent out by NRC. The researchers, who by then were involved in a very intense effort to develop wind technology, would say that they "could not find any better description of how to build a simple efficient windmill". The statement would ring true for many years after as well.

The humble Klein windmills would stand proudly in the 1980s along with the sophisticated, industrial-scale Darrieus systems as something ordinary Canadians could use to improve their personal lives.

The Prince's Cigarette Box

The 38-year-old windmill innovation and discovery was one of the many George stories told by friends and colleagues with a mixture of amusement and awe. There were many.

"George loved making models so much that he invented a machine to make models", some would say in reference to his contour milling machine, a machine that he built to partially automate the craft and art of making model ship hulls for research in the marine test basins. Others would talk of those who had benefited financially and professionally by applying ideas that George had thrown out in casual conversations as merely interesting thoughts for discussion. Sometimes through formal projects, such as the one that led to improved commercial air compressors or the development of the "cyclone" air cleaner that worked with 99.9% effectiveness in dusty manufacturing plants in the 1950s, Klein had an obvious bottom line impact on specific businesses.

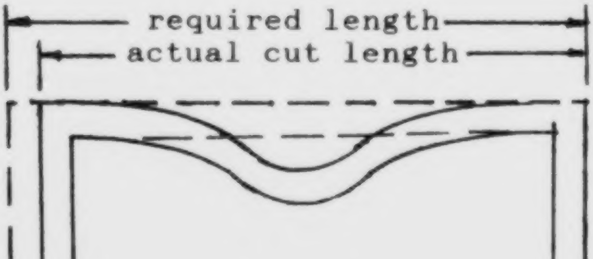
The image that flowed through many of the George stories was, again, that of a visual thinker and one who could convert ideas into drawings with ease. He was said to produce freehand schematics and plans that looked liked they had been drawn with the instruments and skills of professional draughtsmen.

Klein did not really need to call upon those skills. He benefited from excellent support from the machinists, crafts people, technicians, and other engineers that served in his group and the NRC shops over the years.

But on at least one famous occasion, there was no choice, but to draw a picture. The story is most often recalled as the "one about the Prince's cigarette box".

NRC has been visited often by Prime Ministers, Governors General, and other dignitaries over the years, and for a time, it was customary to present the visitor with a unique memento from the NRC shops. Lord Alexander of Tunis came to NRC to lay the cornerstone of the High Speed Aerodynamics Laboratory in the early 1950s and received, as his souvenir, a paperweight shaped like the wing of the CF-100 fighter planes, which had been tested at the NRC facilities.

In July 1954, His Royal Highness, Prince Philip, Duke of Edinburgh, toured and number of NRC labs, starting appropriately with a cruise aboard an NRC research vessel from a dock near Ottawa's New Edinburgh neighbourhood.[365] The Duke, it is said, was to be presented with a cigarette box made in the NRC shops from thick stainless steel. "But when it came time to cut the rough outer shape of the rectangular main body, disaster struck".[366]



A Friend's replica of George's drawing for the Prince's cigarette box *(Klein Family)*.

The box would need to be a specific size because cigarettes of interest to Royalty, unlike the roll-your-owns in Klein's pockets, had standard dimensions. With the Prince's arrival looming, the NRC machinist mistook a mark on the steel as the cutting line, and the piece intended as the top of the metal box was cut too narrow. Only slightly too short. Yet there was no material left to try again. The deflated machinist and disappointed staff were faced with losing an opportunity to serve and associate with Royalty and do their group proud.

Fortunately, George happened by, looked the chopped piece of steel for a few seconds, and took out a piece of paper. His pencil and hand casually showed how remaining pieces could be cut in the shape of a very gentle, but specific hourglass. This meant that the sides of the box could be curved slightly inward in a concave fashion pointing the edges of the side material horizontally and just under the top, thus compensating for the lost width.

A box of the requisite length with the artistic flair of concave sides was quickly produced, the edges were machined to erase evidence of anything awkward, and the Prince was suitably thanked upon the conclusion of his visit to NRC.

Long after the identity of the famous visitor faded from individual memories, the story of the box and the openness and ease with which Klein envisioned and shared a solution persisted. Facsimiles of the organic, artistic, hand-drawn box were kept by people who never met Klein and who recited the story with the aura of a folktale. Anyone who hears it and knew George Klein does not hesitate to accept it as true and routine.

Perhaps the most compelling and awesome story of drawings by George is one that is one that is barely a sentence long.

Designing Jet Engine Research Equipment from Scratch

Early in World War II and not very long after Wing-Commander Frank Whittle's historic first test flight, the British decided to share their new jet engine technology with Canada's NRC to engage it in research particularly around problems with operation in cold weather. The NRC would pioneer this aspect of jet engine work until its Winnipeg facilities were transferred to a C.D. Howe conceived Crown Corporation, Turbo Research Limited. Turbo Research was later dissolved and absorbed into Canadian industry, notably A.V. Roe (Canada) Ltd., which would begin its immensely efficient and internationally triumphant Orenda jet engine project in the post-war period.

During those first two years at NRC, jet engine researchers were struggling to catch up and come to grips with this completely new aerospace technology. The challenge was magnified by the wartime barriers to traffic across the Atlantic and the special difficulties around secret and strategically important innovations. NRC was compelled to start research on the thrust properties of jet engines without the necessary testing equipment and without even the means of building it.

Only the overall assembly drawings were available to the Canadians. That is all. Klein was called in to do what would later be known as "reverse engineering" or figuring out how to make a duplicate. The process required that Klein imagine and then draw detailed diagrams of all of the component parts of a remote, thrust measurement system called "the percimeter". The work would have been challenging and puzzling even if Klein could draw in all of the available expertise at NRC. Yet wartime secrecy meant that few details of the jet engine research could be shared.[367]

He did the job, and more. His report on the project includes a single, modest, but telling sentence: "*the drawings were not materially delayed by introducing several improvements in design*".[368]

He had to do the drawings anyway, so he thought he might as well improve on the new, mysterious jet engine research as we went along since it would not take him any extra time.

"It was the success of STEM that made it possible to establish Spar as a separate company and that gave us the credibility to sell NASA on the Canadarm project"[369]*...*

the American companies lost the battle ... (they could no longer) portray Canada as technologically primitive ... STEM ... had been sold all over the world...[370]
John D. MacNaughton,
Former President of Spar Aerospace Ltd.

9. FINGERPRINTS ON THE ARM

He looked down at his fingers and folded the paper as he had thousands of times before. It rolled back and forth creating the familiar tapered, tobacco-filled tube. He did it with the unconscious ease that comes with a well-honed habit and a ritual that relaxes and distracts. But this time Klein felt something different.

It was 1951. George Klein was on board ship about two days out of Liverpool heading back home from meetings abroad watching the dark, rolling waves of the North Atlantic when the rolling cigarette paper gave him an idea that would draw a line between the *Silver Dart* and the space age, touch the surface of the moon, and become known as his greatest invention.[371] It would be linked to thousands of careers and help give Canada a unique international profile as an inventive, technologically advanced country.

It would spawn over a hundred original products and other patents; be used by all branches of the military and by many industries; it would play a role in some of the most sophisticated and important national projects in the U.S., Europe, Japan, and the Soviet Union; it would not only help bring Canada into space, but be cited decades later as the direct ancestor of components of the Space Shuttle, the Hubble Space Telescope and the International Space Station.

George Klein smoked roll-your-own cigarettes most of his life and never thought much about the casual act of making and smoking them.

"He smoked them right down to the very end, and I remember talking to him one time when a small piece of the cigarette was still stuck to his lip", said a former colleague years later. "I don't know what we talked about that day, but I will always remember the sight of that piece of cigarette moving up and down".[372]

This day in 1951, as he rolled the cigarette, he was also rolling a persistent and nagging problem around in his mind. It was, once again, a military problem.

A Funny Robot Beacon Helps to Save Lives

Klein and his NRC colleague Harry Stevinson had gone to Britain charged with developing a special kind of radio beacon that could be dropped into military target areas to help guide aircraft over difficult terrain or even over enemy territory. The project had many unique challenges embedded in it.

If the beacons were to be dropped in areas where Canadian aircraft were not welcomed, they would have to be dropped from a high altitude. This meant that the beacons needed the protection of a durable container and would need a parachute of some sort. The beacons would also need a long antenna to send signals to aircraft travelling at great heights and over long distances.

The dilemma rested, as usual, in the contradictions between the technical requirements. A long antenna would not only risk damage flying through the air or landing on rugged terrain, it would also tangle the parachute on the way down. Klein and Stevinson also knew that the ideal, and possibly only practical, beacon for this purpose would need an antenna that pointed straight up.

Klein saw the solution to one set of problems in his cigarette. After he put it to his lips, lit it and smoked, he took out another paper and rolled it back and forth, this time with no tobacco. As he did, he noticed two phenomena. First, the rolled-up paper had more tensile strength than a piece of unrolled paper. Second, once rolled into a tube, the paper could be extended out considerably.

It looked like a long pole. It looked like — a radio antenna.

Many years later, former colleagues would tell the story claiming that "George got the idea while rolling cigarettes in church". But Klein and others would correct them with the mild amendment that he merely drew pictures of it in church. The antenna design based upon the cigarette paper was akin to rolling out a concave steel measuring tape, which can be coiled up into a small cylindrical case and then unfurled.

George Klein rolling the next day's supply of cigarettes as he did every night *(Klein family photos).*

But the simple rolling up and unfurling of a long thin piece of heat-treated metal was not enough to constitute a new invention or mechanical device. It needed a system of springs and gears that would smoothly and consistently induce the unfurling metal strip into the tube shape for greater stiffness, straightness, and strength.[373] Fortunately, over the years, Klein had developed that knowledge and become an expert in gearing systems. The combination of his inspiration, education, and the motivation of the problem came together to make something that worked.

When first asked, years earlier, by his colleagues to help with work on gearing systems, Klein was reluctant merely because he had so many other projects on his plate. But it was his job, as head of the Division of Mechanical Engineering's Engineering Section, to do whatever was needed. After he overcame the initial hesitation, his childhood in his Dad's watch making shop came flooding back through his soul. He became both expert and passionate in gear design. Later, Klein would find himself building toys for his grandchildren and amusing himself with complex gearing systems outside of work. Gear devices seemed to flow from his imagination like water tumbling down stairs.

Klein and his team were thus able to develop his rolled metal tube idea with its consequent mechanical gear system to the point that a useable and dependable beacon antenna of up to three metres long could be created from a very small round container. The container would still have room left over for the beacon's electronics and for the equipment needed for remote operation.

Yet the innovation would not be much use to the parachuted beacon if it were to land, due to mishap or rugged terrain, with the extendible antenna pointing down or sideways into rock. It had to point up.

Klein and Stevinson found an ingenious solution to that problem too by devising a simple, but unique "righting mechanism".[374] The cylindrical case containing the radio beacon and its rolled up antenna was thus wrapped, by two broad, flat pieces of steel heading in opposite directions. These strips embraced the round case tightly against its sides like springs ready to pop open but held by a special lock. The lock was radio-controlled, and when the beacon was safely dropped and on the ground, it could be released remotely. The steel bands would spring out to the sides "like the outflung arms of (a) man lying on his back on the ground".[375] The arms were configured such that they would automatically position the beacon to extend the antenna upward no matter what the conditions or how it had landed.

Anyone could throw the little round case onto any kind of surface and release the lock remotely to see the case right itself, extend its rolled-up antenna, and immediately convert itself into a "ten foot tall" messenger.

The beacon was officially a product of NRC's Flight Research Section at the RCAF airport outside of Arnprior, a then rural area north of Ottawa.

It was demonstrated there on a number of occasions to defence department officials, army officers, pilots, engineers, and scientists. They were impressed, and the beacons were duly made and used by the military.

Even 50 years later in a world saturated with electronics and remote controlled toys and robots, it would be an impressive sight. In the early 1950s, it made eyes "pop out"[376], and it seemed like a scene out of a gadget-filled Hollywood spy movie or TV show.

Two decades later, Klein's invention would, in fact, be featured in a television episode of *Mission Impossible*.[377]

Yet as impressive as the combination of beacon, righting device, and extendible antenna was, it was not to be the most enduring output of the project even though the beacon system was put into production and worked well.

Stevinson was a bit disappointed by the intriguing little toy that he and Klein had created. He could see that although it was an amazing, even entertaining device that met the prescribed need of the time, it would not serve the purpose that most consumed him. Stevinson was longing to create a radio beacon that could survive plane crashes.

As an engineer in the NRC aeronautical research labs since 1945, Stevinson, like Klein, had contact with many of the most adventuresome military and civilian aviation figures of the time. Adventure meant danger. Danger too often meant tragedy.

Klein on board ship in the North Atlantic with Crash Position Indicator inventor Harry Stevinson *(Klein family photos)*.

Stevinson, Klein, and their colleagues felt a special kind of pain each time a plane went down particularly when it carried one of the military crews they had met in their work or when the pilot was someone that they admired for pushing the limits of northern exploration and development. This special pain came from a sense that a way to help rested in the technologies and expertise staring back at them every day in their 1950s NRC laboratories.

The funny radio beacon device invented with George Klein magnified this sense and passion. It suggested that almost anything was possible and worth pursuing.

Eventually, Stevinson would build the world's first effective Crash Position Indicator or CPI for airplanes. Over the following decades, it would pass from development to production and sales. It would not only save lives, it would help foster Canada's high technology industry in a unique and powerful way.[378]

By the mid-1970s, Stevinson's CPI was being manufactured and marketed internationally by the Avionics Division of Leigh Instruments Ltd. in Carleton Place, Ontario. The invention was earning millions for the firm.

The device differed significantly from the beacons developed with Klein's rolled up antenna. The early Klein-Stevinson beacons involved too many innovative, but complicated and vulnerable external features: a special parachute, shock absorber, orienting arm system, flotation bag, and extendible antenna. Attempts to try and make it work in crash tests using a mortar firing system had only limited success. In any case, few plane crashes allow time for even the simple act of firing a mortar shell.

In the end, the funny little robot beacon that Stevinson developed with George Klein would merely be a step toward the CPI invention. It gave a hint at the possibility and provided lessons on what to do and not to do for crash situations. Stevinson built a new system with an enclosed transmitter and antenna: all in one package. Aircraft companies could mount the device externally on the plane's body and attach it with a spring-loaded latching mechanism, which released on impact. The air rushing against the leading edge would strip the CPI away from the plane almost instantaneously. At the same time, the shape chosen by Stevinson would provide "enough lift to carry the beacon to a safe distance away from the crash scene but produce enough speed-reducing drag to land safely nearby".[379] The Stevinson Crash Position Indicator was enclosed in a tough protective covering with shock absorption material inside. It was fire resistant, and it floated.

As he wrestled with these problems, Stevinson, like many people at NRC, enjoyed bouncing ideas off of Klein, and Klein, like many people at NRC, enjoyed seeing Stevinson's success.

The United States Air Force, government agencies in other countries, and private aircraft firms adopted the Canadian – built CPI, and although black box flight recorder technology was developed and improved by many institutions around the world, the obvious benefits of merging these systems with the CPI technology were soon recognized.

Leigh Instruments was eventually absorbed into other corporate entities, but not before recording many years as an outstanding commercial success manufacturing and marketing the product that also made aviation safer internationally.

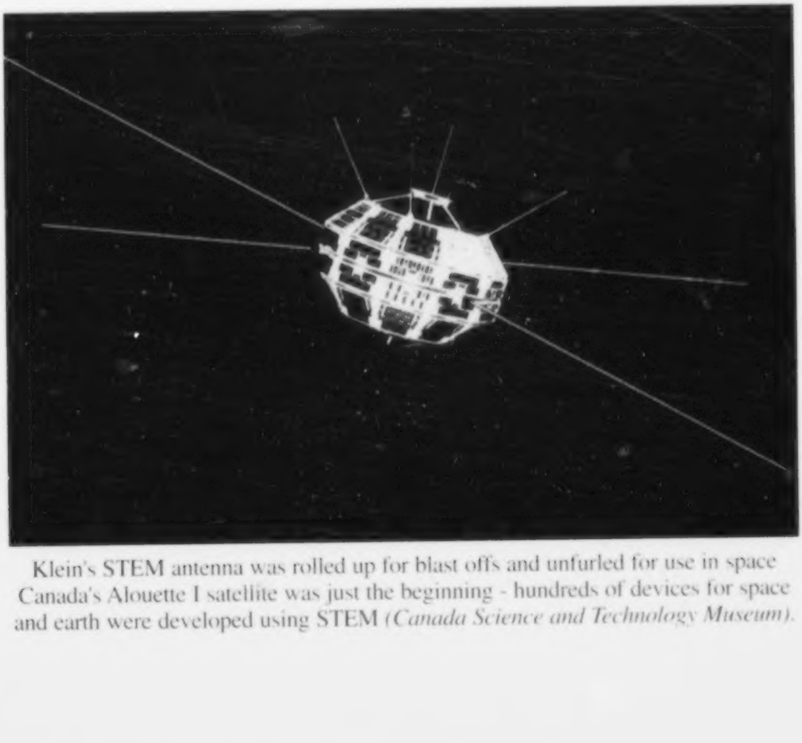
The Space Antenna that Spawns a Hundred Innovations

As Stevinson continued to pursue the passion of his career and as Klein moved on to other technical challenges, the world was changing.

The Cold War of the 1950s seemed to reach a height in 1957 when the Soviet Union launched Sputnik, the first man-made object to enter space. Sputnik caused anxiety in many countries and in many powerful circles, as it seemed to burst upon the world's media as a shocking demonstration of Soviet technological superiority and an event that implied darker possibilities.

Yet it was not much of a shock to the scientific community in Canada.

The radio engineers and scientists participating in international conferences and collaborations where Soviet scientists were present had realized earlier that their colleagues behind the Iron Curtain were close to launching the first satellite.[380] Within hours of Sputnik's launch, a group of engineers and scientists working at defence research facilities on the west side of Ottawa were not only aware of Sputnik's existence, they were tracking it and projecting its orbital path.[381] These were the professional descendants of the impressive Canadian research teams that developed and applied radar technologies during the Second World War. After the War, the defence research programs that had been responsible for the early electronics and Radar work were moved out of NRC into a new entity, the



Klein's STEM antenna was rolled up for blast offs and unfurled for use in space Canada's Alouette I satellite was just the beginning - hundreds of devices for space and earth were developed using STEM *(Canada Science and Technology Museum).*

Defence Research Board, which acted as the civilian research and development arm of Canada's Department of National Defence.

The Canadian Defence Research Board comprised the group tracking Sputnik at the Defence Research Telecommunications Establishment (DRTE) in Ottawa. A little over a decade later as the broader public interest in telecommunications and telecommunications technologies grew, the DRTE would be transferred to the Federal Department of Communications as the core of the Communications Research Centre (CRC).[382]

In 1957, the people working at this offspring of NRC and forerunner of the CRC were not merely tracking Sputnik, they were thinking about their own interests in outer space. As communications experts, they knew that vast regions of Canada, an enormous country sparsely populated and thinly linked, could only be reached by radio communications: radio signals that bounced off electrically charged particles in the layer within the Earth's envelope known as the ionosphere. The ionosphere was an important feature of communications in many countries, but because the ionosphere is disrupted by the magnetic North Pole, which sits within Canada's northern borders, it is a feature of special interest and responsibility to Canadians.

It is a feature of the boundaries of outer space.

NRC, meanwhile, was already sending sounding rockets into the upper atmosphere with scientific payloads that had to withstand stresses and communicate back to the ground.

While American scientists probably knew as much or more about the Soviet lead in satellite technology, their government seemed stunned by Sputnik and responded, as usual, with money. New funding programs to develop satellite technologies and to support viable projects were established in the U.S. Within this environment, Canadians saw a new opportunity to attack their problems with the ionosphere. With a satellite, they could study the ionosphere with an entirely new perspective: from above and from afar.

Whether it was a combination of all of those years of radar experience, a focus on a specific problem, or the enthusiasm of the key players, the Canadians led by the DRTE teams managed to assemble the resources needed to develop and build a Canadian satellite and secure U.S. launch services. The result would be the *Alouette I* satellite, the instrument that made Canada the third country, behind only the U.S. and the Soviet Union, to reach into space.

George Klein with prototype STEM system *(NRC).*

The Canadian satellite incorporated many sophisticated technologies, but it would become renowned for its inclination toward simplicity and durability.

It would also be recognized for its odd appearance characterized by long, spike-like poles sticking out from all sides.

The *Alouette I* posed many technological challenges, which is not surprising for a device that was tackling a special scientific problem literally at the dawn of the space age. The DRTE scientists were well equipped to find answers to most problems, drawing on new innovations like solar panels, special sensors, and transistors. Yet one stumped them. It was the need to design an antenna system that would be large enough to send signals and data hundreds of kilometres back to earth and yet solid and compact enough to withstand the shaking, the force, and the pressures of a blast off that broke the bounds of gravity and the Earth's atmosphere. The puzzle was solved when one of the scientists recalled seeing an amazing little device being demonstrated at the RCAF hangar in Arnprior almost ten years before.[383]

They tracked down the NRC engineer responsible for that antenna invention: George J. Klein. Klein would soon see his device patented by NRC and licensed to de Havilland Aircraft of Canada, a company that had a government contract to build subsystems for the *Alouette I.*

De Havilland staff also recognized the Klein invention as the solution they needed.

In fact, de Havilland engineer Jim Taylor later said that he and his colleagues had been working on their own antenna design. But when he came to Ottawa and saw the clearly superior Klein invention, he walked over and "dropped (the de Havilland) triangular model into (a) wastepaper basket" to show his appreciation for Klein's device.[384]

The device was dubbed STEM for Storable Tubular Extendible Member.

The development and production of STEM was assigned to de Havilland's Special Products and Applied Research Division (Spar) where some of the firm's most inventive and creative engineers would take Klein's basic invention and fine tune it for easy production and eventually for other applications.[385]

The Klein "unit" that the engineer Taylor had seen in Ottawa and took back to Toronto on his lap on the plane "became the precursor of all STEM development", "the seed for (the business's) steady recovery and eventual success", and "the ancestor" of much more complex and ambitious space projects.[386]

Alouette I was a great success and was soon followed by *Alouette II* and the *ISIS* satellites, which also focused on studies of the Canadian concern, the ionosphere.[387] STEM was not the only element of these technological successes, but it was a very visible one and key to a number of the related high profile experiments.[388]

It was also an innovation that lent itself to larger scale production than most devices used in outer space. The marketing staff at de Havilland not only saw potential for STEM within the growing NASA space program but also as a technology to be used in products such as masts and antennae for ground and marine transport vehicles. Eventually, the line of STEM-based products would include items such as the electromechanical arm for elevating the flashing lights on police cars and other emergency vehicles. [389]

Soon de Havilland's Spar division had dozens of people working on STEM products with sales in the many millions of dollars. Customers, notably NASA, used STEM in a variety of applications. The early manned space programs, Mercury, Gemini, and Apollo, all used STEM masts or antennae. STEM was even used to end some of the unnerving blackouts in communications with astronauts and to collect and record subsurface data transmitted from the moon during the final manned lunar mission.[390]

The U.S manned space program was, but one, albeit high profile, application for STEM. It was also used in a wide range of inventions and space products involving communications, astronomical research, and other scientific spacecraft as well as military applications. On the ground and on the sea, the technology was used in a boom to elevate camera systems, a winch for hydrodynamics work, a pole to raise floodlights, legs on survey tripods, and a tool to load industrial ovens and move equipment in dangerous mines and nuclear facilities. It was, of course, also useful in a variety of non-space communications applications from buoy beacons to infantry field radios.

Even though STEM proved to be a great business line for De Havilland, the employees most involved still felt that the firm did not recognize the device's full potential.

In 1967, Spar was spun out as a separate company from de Havilland, which wanted to concentrate on the seemingly more stable and profitable aircraft business.[391] John D. MacNaughton, an early de Havilland Spar employee who later became President of Spar Aerospace Ltd., said that the growing market and success of STEM products was the reason Spar's management and employees had the confidence to make the leap and create their own firm founded on space business. Other product lines would come, but space remained a special focus.

It was a heady time for many people including George Klein. He found himself in an unusual and slightly awkward position. He was in the media promoted by some as "Canada's Space Man" and being celebrated for an invention he had hardly touched for ten years. NRC was pleased to see one of its employees being recognized as a great inventor, and it was especially gratifying when the accolades were being led by Spar, a new and promising industrial interest.

Spar might have had many good and legitimate reasons to downplay or even disregard Klein's role in STEM. The firm's staff and their collaborators at the DRTE deserved at least equal if not more credit for some applications. They needed to adapt it both for space and for efficient production. It demanded innovation and vision at least on a par with Klein's original insights.

Spar, as a new company looking to make its mark in the world, could easily have seen benefit and profit in claiming as much credit for the innovation as it could. However, there was also a commercial and strategic advantage in acknowledging Klein and NRC.

Spar wanted to break into the U.S. space program and military markets with a product that had the two-sided qualities of being something of special strategic national importance and yet something based on a simple and elegant design. The latter presented the potential for easy reverse engineering and copies. It thus helped the firm to be working with a publicly celebrated, well-established Canadian government patent under an exclusive license and under, at least ostensibly, the eye of the inventor himself.

Over the years, the firm would have to contend with nuisance patent infringements and court cases in the U.S. and struggle to defend the NRC STEM patent against surprisingly well-subsidized adversaries who always coupled legal arguments with allusions to the U.S. national interest and Spar as a foreign company. Finally, Spar acquired a U.S. subsidiary and moved some STEM production to a plant in Southern California. The lawsuits and competition seemed to melt away afterward.[392]

Canada had lost some manufacturing, but within a few years, it would show that it had not lost its competitive advantage. It was too late to save American firms from the technological advances and competitiveness that STEM had implanted in the Canadian space industry.

Whether Spar's motives in celebrating NRC's George Klein as the inventor of its critical product line were mixed or not, it is unlikely he could have withstood the spotlight and the professional jealousies that this attracts had he not been praiseworthy and deserving on a fundamental level.

Klein felt uncomfortable in media interviews and public events even though he liked talking about his work. He was very much the archetype Canadian: a genuinely nice man, generous and unassuming and yet clearly talented and clever. It was easy for others to attest to the latter qualities after being exposed to the first, and the tag of STEM inventor had stuck with increasing adhesion as the 1960s unfolded.

His role as the inventor of the STEM technologies was raised again and again in the years ahead as the profile and achievements of the Canadian Space program grew. This, in turn, led some writers and specialist researchers to scratch a little deeper. As they pulled back the covers on his career, more stories flowed out: stories that had been buried by military secrecy, modesty, and mishap. Slowly a full picture emerged, and while Klein may have, at times, been credited a little more than he warranted in respect to all of the STEM-related inventions and successes, the accolades seemed just in the scope of a lifetime and a career that had so many unrecorded and unmarked achievements.[393]

The Old Man and the Arm

In the summer of 1969, a man set foot on the surface of the moon, and George J. Klein marked his 65th birthday and retired from NRC looking back on research that stretched over four decades. His energy and enthusiasm had hardly diminished, and he was hoping that official retirement would not mean the end of working on things that he liked. The notoriety and new contacts flowing from the success of STEM and the space program would ensure that it would not.

Even before the first human steps had marked the surface of the moon, NASA was beginning to envision its next great goal: the development of a reusable space craft, one that could survive blast off and re-entry and be a workhorse in the scientific exploitation of space. It was the genesis of the Space Shuttle.

Canadians including NRC and Spar were well aware of the planning at NASA, and started very early on to consider what role Canadian technology might play in the multibillion dollar Space Shuttle program. The opportunity was championed within the Government of Canada by NRC's Frank Thurston, the man who had succeeded J.H. Parkin as head of the National Aeronautical Establishment, an NRC offspring of the Division of Mechanical Engineering. Thurston encouraged the fledgling Canadian space industry to think big, and one idea captured the imagination of all concerned: going for the remote manipulator system (RMS) work – the giant robot arm. The idea came first from the Toronto area engineering firm DSMA-Acton, which had been inspired by its work on robotics for the nuclear industry. But it took a consortium of interests and expertise to make it a reality. NRC was the lead, but NASA was convinced to entertain the idea because of Spar's success and track record in the production and delivery of STEM and because of the expertise of firms like RCA Canada Ltd. (later part of Spar).[394]

Spar was identified as the "prime contractor" for the project with DSMA-Acton, CAE, and others contributing.

Over the next decade, the Government of Canada invested $117 million dollars to develop and produce the first RMS – which would become known as "the Canadarm". NRC was the organization assigned responsibility for overseeing the project, and the first project manager was Dr. Garry Lindberg, a scientist and engineer, who would succeed Thurston as head of NAE and later the NRC Space Division.

The Canadarm was to be some 15 metres extended and capable of reaching in many directions with many different attitudes. It was to have a shoulder joint, an elbow joint and a wrist joint with each powered by small motors. This meant very large gear ratios and gears, and these needed to be carefully designed with "Zero" tolerances. This called for very innovative gearing, and no one could be absolutely sure how it would behave in space, and no one had built anything like it before.

But Spar had brilliant people on staff including mechanical engineers with a flair for gearing systems. They devised an approach that seemed to work, but it was a big project, risky, costly, and high profile. Lindberg decided he needed to have the mechanical gearing system reviewed by an external expert.

He knew George Klein and his reputation for gearing design.[395]

Klein was at this time a 72-year-old retiree working part-time at the local university. He was a full seven years past his last official day of work at NRC, but did not live far away. He was still living in the old New Edinburgh neighbourhood of Ottawa a few blocks from the NRC's Sussex Drive facilities. Lindberg negotiated a contract for the elderly engineer's services, sent him to Toronto to meet with the Spar engineers, and asked him to draw upon the experience and insights that he had been developing ever since he witnessed, as a child, demonstration flights by the pilot of the *Silver Dart* in the first decade of the century.

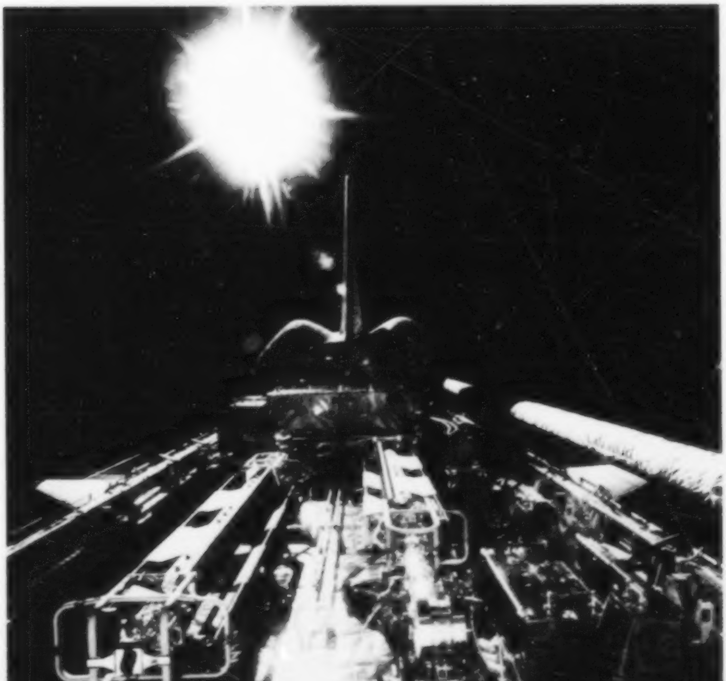
Like most active and bright retirees, George Klein welcomed the invitation to work again. He was excited by the technical challenge that he was being asked to consider, but he especially appreciated the chance to drive to Toronto. He loved that long, peaceful drive as a guilt – free opportunity to daydream and ride in his Ford.

He was being sent in to second guess the experienced Spar engineering team as NRC's "Chief Consultant on Gear Design" for what would be the Canadarm.

George had grown to love mechanical gearing systems as a game that was relaxing and motivating at the same time. Even in retirement, he continued to find fun in designing original toys for amusement using intricate gears and working late nights developing new gearing systems "just for fun".

He attacked the Spar assignment with the enthusiasm of someone who had been given a second chance and someone whose child-like sense of wonder had been rekindled unexpectedly. It was, therefore, not for lack of trying that he eventually concluded that there were no dramatic improvements that he could suggest to NRC and Spar.

He was in a position to influence the design. But just as it would have been wrong to change the Inuit dog sled just for the sake of doing it, it



Well past the age of 70, George Klein was Chief Consultant on Gear Design for the Canadarm *(NASA photo)*.

would be a disservice to try and change what the brilliant engineers at Spar had done. He did the right thing.

While Spar may have adopted some minor suggestions and refinements, Klein's role was essentially to endorse the Spar design. He contributed most in providing comfort to the government's manager. NRC was satisfied. The project went ahead, and its success as a symbol of Canadian technological skill is well known. NRC staff ensured that it would have this publicity effect by negotiating with NASA to have the Canada wordmark and flag imprinted strategically on the arm so that television cameras would turn the device into a giant billboard for a country. NRC's then President Larkin Kerwin introduced the name "Canadarm" in 1981,[396] and Spar and its industrial partners delivered a product that worked with near perfection. The Canadarm's dramatic retrieval of the damaged $250 M U.S. satellite Solar Max and its later repairs to the Hubble Space Telescope would demonstrate its dexterity and value to the world in the decade that followed its first use in 1983.[397]

Buoyed by the success of the Canadarm and emboldened by its credibility with NASA, NRC created the Canadian Astronaut Program and recruited its first six team members. Marc Garneau became the first Canadian in space as an NRC employee in October 1984. Lindberg and his colleagues started looking beyond the Space Shuttle and helped position Canada for a role built around the Canadarm technologies in the International Space Station project.[398] By 1989, these initiatives and Canada's expertise in satellite technologies, communications, and remote sensing from space would combine to create the separate Canadian Space Agency which took not only NRC's Space Division and Astronaut Program with it, but also Kerwin and Lindberg.[399]

The Canadarm delivered by NRC to NASA was a $100-plus million national research and development project with a very clear visible output. With its first use, it immediately turned into a business, and NASA ordered more Canadarms from Spar. Even though the first one worked, the next generation required adjustments to accommodate changing production circumstances and operational requirements. Spar now saw the need for an outside perspective on its own. This time it was working without the same oversight of NRC and of the Government of Canada since NASA was footing the bill.

This time Spar could go anywhere in the world it wanted to seek advice.

But it decided to contract for the services of the now 80-year-old George Klein. Klein had impressed them as Chief Consultant to NRC.

He would be offered airfare, accommodation, and other courtesies along with his fees, but he would again choose to make his trips to Toronto for jobs at Spar by automobile. He continued to work, to daydream, and drive for a few years more. His personal files include invoices for consulting work well into his ninth decade of life: consulting work on one of world's most advanced mechanical devices and one of Canada's most important symbols.

Although Spar would later be assumed by other corporate interests, [400] its robotics division would, in Canadian hands, continue to build upon the Canadarm experience with new robot technologies and new versions of the arm for the Shuttle program and the Space Station.[401]

As George Klein approached the end of his life, he would often watch images from space of the large mechanical arm that carried his country's name and his fingerprints.

"He was a procrastinator of the highest order.
He was a master at it".
Florence Klein
Interview with Author April 2003[402]
and many other occasions

10. BRAINSTORMING, BICYCLES, AND BIRDHOUSES

It came as a surprise. Florence had been married "many, many" years, and her husband never once mentioned that he owned a sailboat let alone that he had designed and built one himself.

They lived comfortably, but modestly with few luxuries. The phone call from the stately Britannia Yacht Club seemed, at first, like a mistake. The Club, well-over a half century old at the time of its surprise phone call to the Klein home, was not only the best known and prestigious in the city, it was one of the oldest in Canada.

The manager at the Club was calling to ask if Mr. Klein would mind removing his damaged and aging "dinghy" from the premises. The Club was ready to start renovations, and this had prompted its staff to finally track down the owner of the small sailboat with a hole in it. It was the personalized little ("15-foot") boat that George had built during the evenings and weekends in the John Street mill buildings shortly after he arrived in Ottawa in 1929.

Unlike many Canadian cities associated with classic images of sailing, Ottawa does not touch upon an ocean, the vast St. Lawrence River system, nor, like Hamilton, one of the Great Lakes. Yet Ottawa is a great place for sailors.

The Ottawa River blends relatively tranquil, sheltered narrows and bays with wide expansions like one called Lac Deschênes that can be both challenging and liberating for even the skilled yachtsman. Yachting is a natural perk of life in Ottawa, and Klein, whose fascination with sailing was manifest in his teenaged crafting of a detailed model boat, saw it as a way to merge his skills and a hobby.

In 1929 and 1930, he designed the boat, as he would so many other instruments in the years ahead, from his own ideas of what would work best, not from any plans or prescribed instructions. All of the fittings as well as the overall vessel shape were products of Klein's independent study of sailing. He even made his own hardware for the boat. After testing and review, he designed and created a hollow, wooden mast that found the perfect balance between a lightness that would make it easy to maneuver and a strength that could withstand the strongest winds.

With some help from a friend at work, Klein painstakingly built his hobby-creation during his off hours over his first years at the National Research Council. It was a beautiful vessel when first launched, and he enjoyed using it and the game of sailing as much as he enjoyed the act of designing and building it.

One day a few years after the boat was christened, Klein returned from a trip to learn that Ottawa had experienced a bad wind storm. His boat "suffered disaster"[403]. It had been blown into the rocks and been punctured. It needed repair.

Klein could never find the time to patch that hole. He loved sailing, and the barrier between having a special boat at his disposal and not was miniscule compared to the many hours of design, testing, and building it in the first place. But he put it off. For decades.

With prodding from the Britannia Yacht Club, he would bring the vessel home and place it in a sling in his garage where it rested for another extended period. Eventually, it would be repaired with the help of Klein's son, of course, another George Klein, and Klein would renew his love affair with sailing. This time he shared the experience with his own children on family vacations in places like Round Lake north of Ottawa. He would take tremendous care and stress those around him in the elaborate processes of putting the boat into the water and of taking it out again. But once out on the water, he would relax, smile, and smoke.

His difficulty in finding time for the routine exercise of repairing a hole was a characteristic of life with George. Over her 52 years of marriage, the eventual patching of the sailboat would be one of the few victories Florence Klein would witness in an epic and largely vain effort to get her husband, the talented engineer and mechanical genius, to make repairs around the house. She often carried this load alone.

"He was a procrastinator of the highest order; he was a master at it", she would laugh, adding that his typical response to her requests was "Let's not rush into it, Dear".

He loved to drive the family Ford and seemed to retain the pride of a man with his first car for all his life. His long drives back to Hamilton as

George and Florence courting at Meech Lake (*Klein family photos*).

one of the rare young men with a job and car during the Depression were a mix of relaxation and brashness that stayed with him until he could drive no more.

Yet he could never make time to keep his cars maintained. He would not even bother to change the oil and could run a car dry before even thinking to top it up.

The image of a languid George at home contrasts harshly with that of the energetic, driven, and uber-producer at work. It was frustrating at times, but he was pleasant about his chores avoidance, and any strains at home were minimal. Still, it seemed strange.

Klein loved Florence and his family, and even though he was often absorbed in his work, he enjoyed family time and managed to focus on the family during vacations and seemingly shut out the pressures and ideas that possessed him throughout most of the year. He would make original toys for his own children and later their children, and when anyone showed interest, he would talk about his work with gentle laughter and enthusiasm.

But making toys and talking about ideas are activities that hold the magical quality of being about "something new". Repairing a sink and patching a hole are not.

George spent his days and his career "always doing something different"[404]. It was, for many, many years, a flood of different things, unusual problems, challenges that befuddled others, and, by the standards of a research organization, immediate feedback on successes and failures. His inventions were almost always used as soon as he perfected them. Unlike the scientist who works for years to unlock a fundamental mystery, Klein would be asked to invent something that could be used the next day.

The military would be waiting to put products like the *Weasel* into mass production; disabled veterans may only need a few electric wheelchairs, but they needed them today; and even when he was working with nuclear physicists, his tools and equipment would be applied immediately albeit in the context of longer-term research.

It was relentlessly and joyously, always something new and different for over 40 years.

As official retirement age approached, Florence Klein knew that her husband would not be content with puttering around the house, helping her in the garden, or even sharing her volunteer work at the local seniors' home.

She was not sure what he would be doing, but she was sure he would find a way to do more driving. He would be using the car more, maintaining it rarely. When he did retire, she bought her own second car just to be on the safe side and have transportation when she needed it.

Neither George nor Florence could have predicted in the late 1960s that his talents would remain in demand for another couple of decades. But as mileage claims to Spar aerospace attest, Florence's apprehension was well-founded, and her husband would still be tying up the car for driving trips to Toronto well into his eighties.

George had hobbies. He played tennis and cross-country skied, sometimes trying to improve his performance with materials and technologies from NRC, and he loved music. The son of the jeweler and watchmaker had learned to play the violin as a boy on a quarter-sized instrument that he later gave to another George to use when he was a child growing up in

George on the violin, sister Marguerite, and grandchildren Laura, Karen, and Steven, making music together at the Klein home in Ottawa in 1983 *(Klein family photos)*.

Ottawa. George, the inventor and engineer, would learn to play well enough for membership in two symphony orchestras.

Until an injured finger curtailed his talent, he played in a trio in his later years as well.

But, as his 65th birthday approached, he knew that he would need more.

In the decade before retirement age, George started laying the groundwork for a postretirement vocation by doing something that was both new and old for him. He began teaching mechanical analysis and design part-time at the School of Engineering at Carleton University. The curriculum vitae that he submitted to the Faculty was more a statement on his modesty and self-effacing personality than a résumé of his true credentials for the job. After dutifully listing his public and high school education and then his B.A.Sc., he begins the list of relevant work experience with the ten months that he spent as a 24-year-old University of Toronto "Demonstrator"/ teaching assistant after graduation in 1928. As for his thirty-plus years at NRC, his CV stated, "Began as Junior Research Engineer in Division of Physics and Engineering. At present Senior Research Officer".

Carleton University management must have known him to be much more when they appointed him the academic rank of "Lecturer" and then, upon his retirement from NRC in 1969, that of Adjunct Professor. Professor Klein continued on at Carleton for many years, enjoying his time with the engineering students; many would identify him as their favourite instructor during their undergraduate years. He would be remembered not only for his technical and engineering instruction, but his special classes and seminars on "brain-storming", creativity, and invention.

Perhaps his lack of graduate degrees and his years as a researcher with ostensibly lower academic credentials accounts for the affinity he showed his students and for his reputation as a professor and a person who "never talked down to" them even when they were very young.

Klein spent time volunteering at the Crichton Street Elementary School only blocks from his home. As a special kind of teacher's assistant, the now very elderly mechanical engineer and inventor would teach the boys and girls of the neighbourhood school to build birdhouses and "to work things out for themselves".[405]

In any case, Klein was one Professor who never seemed to run short of illustrative, compelling and fun stories. Whether they were machine and mechanical design students at university or six-year-olds in the neighbourhod, former students remember his stories and inventions decades later as the most intriguing discussions in their classrooms.

While it would be difficult to calculate the number of students he inspired directly, two that heard all of his best stories, more than once, do seem to have followed his example.

George's "active and talented" daughter Margaret spent her career in education working for the Ottawa Public School Board, and his son, naturally named George as well, became an electrical engineer and one of the Canadian pioneers in a field that his father touched upon in his work with wheelchairs and the suturing device: biomedical engineering.

Throughout the 1970s and 1980s, interest in George Klein's stories slowly started to grow outside the family and neighbourhood, and even outside the university community.

Partly as a function of his association with the increasingly high-profile space program, more and more writers and chroniclers of Canadian innovation were learning of the name George Klein, and a few were digging deeper. As they did, authors, historians, and journalists would initially see Klein as "an unsung hero of Canadian science" merely on the basis

George and Florence on the day he received the Order of Canada. Their children: George and Margaret *(Klein family photos)*.

of his major projects: STEM, ZEEP, the *Weasel*, snow research, and aeronautical engineering. But academics and historians were intrigued as well. And, those who conducted original research, below the layer of official reports, came to the conclusion that he was more than someone with a string of significant projects, but "one of Canada's most prolific and successful inventors and design engineers"[406] and "possibly, the most productive inventor in Canada in the 20th Century".[407]

Klein's retirement was nested in the midst of media-attracting anniversaries and events: the 50th of the creation of NRC (1966), the *Apollo 11* landing on the moon (1969), the 25th anniversaries of the invasion of Normandy (1969) and V-E Day (1970), and the 30th anniversary of the start-up of ZEEP (1975). All revived memories and induced recollections of early research and innovation in Canada. Interviews and retrospectives began to draw out stories that had been kept secret or were lost below the surface of technical reports and scientific papers. When it came to invention, design, and mechanical problems at NRC, one name would be cited more, much more, than anyone else: George J. Klein. Klein's name is, for example, referenced on over 60 pages, roughly 10%, of Parkin's two-volumes memoirs on *Aeronautical Research in Canada (1917–1957)*. The projects Klein touched spill over onto the other pages as well.

While he was a modest and even shy man, who was very uncomfortable in media encounters and constantly diverting credit to others, Klein could be drawn out by interviewers and historians who tapped into his enthusiasm for his work and love of the stories behind his many, diverse projects. A picture would emerge from these fragments and sundry sources of a man who was seemingly involved in everything and who literally influenced thousands of innovations and inventions of special interest to Canada.

NRC colleagues had seen to it that he was made a Member of the Order of the British Empire (M.B.E.) after the war for his contributions to science in support of the Allies, but this honour was bestowed on the basis of many secret projects and, as was the case with other civilian heroes of the war, his credentials for the M.B.E. were not widely publicized at the time. It was, for many years, the only significant recognition of his work.

But right around the time of his retirement this started to change.

While it is customary for accolades, if any are due, to come around retirement time and around one's departure from friends and colleagues, this would not alone explain what came George's way over the last phase of his life.

George was ill – so Carleton University came to his backyard to present his Honorary Doctorate degree in 1988 *(Klein family photos)*.

He received honours from unexpected sources and from high places.

He was not only repeating the recognition of past achievements, but also benefiting from his ongoing involvement, energy and output. New communities, industry, government, and academe learned about his work and learned first hand that he was the kind of Canadian the country might like to celebrate: modest and dedicated to work that helped his country.

In 1969, he was appointed an Officer of the Order of Canada for national-level service to his country. Within a few years, he would be honoured by international organizations such as the Royal Aeronautical Society and the American Society of Mechanical Engineers. He would also become Dr. George Klein. Eventually he would receive a Doctor of Engineering, *honoris causa*, from Carleton in 1988, but the first doctorate would come in the form of a Doctor of Laws degree from the now Wilfrid Laurier University in Waterloo, Ontario – formerly, Waterloo Lutheran University. His Alsacian ancestry and South Western Ontario Lutheran roots had reached out to stamp a defining label on his career and life as, not merely a technical problem solver, but a true inventor, research scientist and servant of Canada.

Klein maintained his energy both mental and physical for over two decades after retirement. Despite his two to three packs of roll-your-own cigarettes per day habit, he kept up his pastimes and even introduced cycling to his regular schedule in retirement.

Life and his body eventually caught up with the man who rarely stopped. He started to age rapidly when told that he could no longer drive his car, but despite the decline, he was still bicycling on one of the Ottawa area's unpaved trails just weeks before his death.

It came on November 4, 1992.

He was 88 years old. The National Research Council of Canada was seventy-six. Both had seen great changes in Canada over the course of their lives.

A boy who had seen Canada's first aviators in flight had grown to touch the surface of the moon and the Space Shuttle with his inventions, and the organization he helped to build had grown from an idea to a pervasive influence in Klein's country.

"No organization" stated the Preface to the Canadian Science and Technology Historical Association's book *Building Canadian Science* published just before Klein's death, "… has had such a profound influence upon the growth of science and technology in Canada as the NRC".

In 1991, to mark the 75th anniversary of NRC's conception, a collaboration of institutions including the then National Museum of Science and Technology (now Canada Science and Technology Museum) came together with NRC to create the Canadian Science and Engineering Hall of Fame to honour the Canadian "giants" of the fields. Nobel Laureates such as insulin discoverer Sir Frederick Banting and father of molecular spectroscopy Gerhard Herzberg and science statesmen such as General Andrew McNaughton and E.W.R. Steacie were inducted to set the bar and standard for those to follow. Inspiring role models such as disabled aeronautical engineer Elsie MacGill were also included. Only one or two inductees are typically added to the Hall of Fame annually.

In 1993, the next year, the then late George Klein was chosen. The Museum would later add exhibit space dedicated to Klein's inventions.

Even as recognition and promotion of his life and career made some advances, as the century marked by his work came to a close, the feeling persisted that something more could be done. This biography was commissioned by the publishing branch of NRC, a part of the organization that also traces its creation to 1929, the same year George Klein came to Ottawa to help build the institution and serve Canada.

Klein's influence extended far beyond NRC and touched many fields, but his most pervasive impact may have been through the example of his work and the uniquely Canadian approach to innovation it induced.

Whereas in the U.S. the profession of industrial design began as a method of sales promotion, "concerned with product styling and packaging", Canadian industrial design has developed with a much stronger association with engineering, science and technology.[408] Industrial design became firmly established in Canada after 1945, as a direct result of the development of secondary industry fostered by research and innovation on wartime problems at NRC and elsewhere.

After the war, C.D. Howe, then the federal Minister of Reconstruction and a strong supporter of NRC, directed that a special exhibit on the design and inventions at the National Research Council be developed to help promote and preserve this expertise in Canada and to promote the link between design and technology. The exhibit of NRC invention, which had been defined by Klein's work, was developed and officially launched in 1946 at the annual convention of the Canadian Manufacturers' Association and then travelled across Canada. Afterward, those responsible were charged with developing recommendations based upon this experience, and these recommendations, in turn, led to the national Industrial Design Act of 1961 and the founding of the National Design Council, a policy and promotional body which not only "had great impact on Canadian design and which became a model for many design councils in other counties".[409]

During the same period in the wake of the NRC driven, wartime innovations, industrial designers began to organize as a profession. In 1946, the Affiliation of Canadian Industrial Designers was formed, which by 1947 had incorporated itself as the Association of Canadian Industrial Designers.

These great Canadian industrial design talents showcased in the exhibits and buildings of the Expo 67 World's Fair in Montreal, in many other venues, and in many consumer products echo in a small way the inspiration of Klein's early work at NRC and his creativity in engineering, invention, and design.

Creativity and innovation are widely seen as the product of a complex formula that draws upon emotional strengths such as determination and will as well as intellectual resources and technical skills, all inspired and fuelled by imagination.[410]

Klein's talents and productivity certainly fit this mould. Although he lived through a dramatic period and family challenges, his life was spared the worst of the times and was supported throughout by an enthusiasm for his kind of ingenuity: first among the Hamilton watchmakers and later among his engineering-inclined family and place of work. His education, talents, and technical knowledge were magnified by that of his colleagues in the Division of Mechanical Engineering and, indeed, all of NRC.

Finally, his imagination and capacity to visualize gearing systems and technical solutions before they existed were increased dramatically by the steady, relentless stimulus of specific problems, requests for help, and challenges requiring his kind of creativity. The work was appreciated and rewards reinforced the process again and again.

Problems are, in a sense, clearly imagined objectives that can motivate and offer an opportunity and framework to mobilize the intellectual and emotional resources in the quest to create something new.[411] Klein was this kind of "creative problem solver".

In 1996, Carleton University would introduce the recognition George Klein may have appreciated most. It established the George J. Klein Medal as the top prize for the national High School Industrial Design competition to celebrate students who show a special kind of creativity: one that blends engineering-style skills and appreciation for the practical demands of the real world with the imaginative and visual skills of the artist.

They will be Canada's creative problem solvers of the future.

Explaining the workings of a sailboat to his Grandson, Steven 1979 *(Klein family photos)*.

If a Canadian had invented the light bulb, the world might have remained in the dark for another decade....

But... if Edison had worked at NRC, he could have invented it ten years sooner.

APPENDIX 1. EDISON AND KLEIN

Thomas Alva Edison was brilliant, persistent, inspiring, inventive on many levels, and wise in many fields of research. Even before his 1931 death at the age of 84, Edison had changed the world for the better through his combinations of ingenuity and industry. Phonographs, motion pictures, telephones, and power generation were all defined in significant ways by his ideas and his works.

His version of the incandescent lamp, the glowing electric light bulb with its heated filament line, still stands as an international symbol for inventiveness well over a century after its unveiling. In Menlo Park, New Jersey, Edison established and ran the world's first true industrial research laboratory, an innovation that could stand on its own as a potent global influence even if it had failed to produce a single marketable invention.

But it did produce many.

The most oft cited number to quantify Edison's genius is 1,093.[412] This is the number of patents that bear his name. The figure established the record and would dwarf the patent statistics of his most brilliant and commercially sensitive disciples in invention. Edison was inherently capable. Yet students of his life feel that he likely would never have achieved such success had he been a Canadian.

> *"The world might never have heard of Thomas Alva Edison if his family had not been forced to leave their home in the small village of Vienna in Upper Canada (what is today the province of Ontario). The young Edison would have found a more sedate economic and industrial environment in Canada than he did in the United States, one that did not emphasize invention and innovation".*[413]

Edison's family was of Loyalist stock and lived, paradoxically, in the same time period and in the same region of Canada (South Western Ontario) as George J. Klein's great grandfather, the European farmer who had crossed the Atlantic for a better life. Around the time that George Klein's grandfather was born, Edison's father, Sam, who found himself on the unfortunate side of William Lyon Mackenzie's 1837 Rebellion in Upper Canada, fled the region to the U.S.

Sam was later joined by his wife and children. After their relocation to the U.S., his wife gave birth to others, but only one of her American born survived.

Thomas Alva was born in the U.S. on February 11, 1847 in a small town in Ohio, the State that would later be the venue for training George J. Klein's father in the profession of watch making. While Edison spent summer vacations in Canada with his Canadian family as a child and would even invent and work as a young man as a telegraph operator in Stratford, Ontario, his formative years and productive life were eminently American.

The perception that U.S.-style capitalism, private enterprise, and individual promotion provided a better environment for his successes is likely sound since Edison's capacity to pursue his dreams and bring them to the world were a function of his access to capital and his own personal business bent. He was supported by the great capitalists of the period in his quest to perfect the electric light bulb, and he was driven to commercialize his invention by material as well as professional rewards.

Is it possible then that a Canadian, George J. Klein, could have been as productive an inventor as Edison ?

It is — if the measure of an inventor's productivity were to be limited purely to the total number of ingenious new and useful devices, processes, and designs that an inventor generates for others. Klein was exclusively and simply productive in this sense.

The number 1,093 (barely a couple per month on average) would be a feeble estimate of the number of times George Klein performed the feat of invention over his 40-year career. He came to his lab each working day from the Fall of 1929 to the Summer of 1969 either attacking new designs and innovations in progress or facing a new one coming through the door.

Yet unlike Edison, Klein had almost no interest in patents.

After all, a patent's explicit intent is to create a right to exclude others from making, using or selling the invention. Paperwork aimed solely at protecting or restraining the output would have seemed like an abhorrent administrative task. Klein operated and pursued his innovations without this concern hanging over him.

Klein designed and created inventions for others and anyone who could use it. It was his job, and he assumed that sharing his inventions freely was also part of it. In fact, he energetically gave his ideas away. When serendipity led him to recognize the business potential of the STEM antenna, he and his NRC colleagues tried to interest British science and industry to take it and use it for a handshake. Only when a Canadian firm seized the opportunity a decade later did the advantage of a government-held patent become apparent.

The Klein wheelchair, which embodies many, many innovations, was, of course, given away freely with the knowledge that NRC and the Canadian Veterans Affairs production teams could not meet the civilian and international needs. Klein went to great lengths to ensure that the technology was known and freely available as a mechanical version of a vaccine or cure. A Canadian had, after all, years earlier shared the Insulin treatment for diabetes without patents or profit.[414]

Most of Klein's innovations were embedded in the work of his colleagues as subcomponents or as supporting research equipment. As a consequence, the quantitative measure of his output lies in general records such as requisitions for original devices from the NRC shops or the Division's Laboratory Technical Reports. Ultimately J.H. Parkin reviewed each and every one of these documents while Director. "Like the toughest university professor ever", he marked the technical papers up, sent them back for amelioration, or rejected them if they did not reflect genuine innovations and advancements.[415] As one of the most knowledgeable and, at times, the most knowledgeable Canadian in a given field, Parkin would have made for an extremely competent and stringent patent examiner in mechanical and aeronautical engineering during the period.

Some experts suggest that Klein contributed to virtually all of the mechanical design work and invention of the Division laboratories during his four-decade career.

"Almost without exception, where the hand of the skilled mechanical designer was needed in DME (the NRC Division of Mechanical Engineering), George Klein's influence was felt" wrote Ian R.G. Lowe, Former Director of DME and Past-President of the Canadian Society of Mechanical Engineers.[416]

A more reserved estimate of Klein's involvement in the Division's work might be 10% given that this is the relative space allotted to his work in reports such as the *Parkin Memoirs* and the *War History of the Division* *of Mechanical Engineering*. Even this humble estimate of his influence would put the quantity of Klein's inventions and innovations in the thousands when projected over his career.[417]

In producing designs and inventions in quantity, Klein had several advantages.

First, he and other 20th century inventors were all standing on Edison's very broad shoulders. Edison forcefully and doggedly installed the infrastructure that ensured his genius provided a foundation for others to build upon and to invent more easily.

The inventors that came along in his wake would ride upon machines and greater research options powered by Edison's work. While Klein's 1930s laboratories and shops seem humble by 21st century standards, they were wondrous and magical compared to the tools Edison had at hand during the height of his potential, 50 years earlier.

Edison's passing, coincidentally, came within months of the inauguration of Klein's first research facilities at the NRC John Street labs. The Klein wind tunnel was made operational when the Ottawa electric company provided power through lines that had to be specially installed. Later in 1931, Klein and the NRC researchers would set up permanent power systems using their generation plant at Rideau Falls. Edison's spirit was all around them as they worked.

Klein's work would also be empowered by the atmosphere of respect and support that all inventors enjoyed because it had been cultivated by Edison's life and reputation. Yet Klein also travelled upon the crest of another wave: the transition from the era of the empirical, workshop inventor to the modern professional scientist and industrial researcher. Klein was fortunate in that he rarely had to choose between one mode of innovation over the other as he constantly moved back and forth between the two.

Klein was also able to demonstrate "astonishing" talent and productivity in invention because, unlike the great American, this Canadian had the luxury of focusing almost entirely upon the act of invention. Edison was split by his persona as an inventor, an entrepreneur and an industrialist whereas his Canadian counterpart was the employee of an organization dedicated to invention and innovation for its own sake and for others.

Edison's patents and successes were as much a product of his multipronged ambitions as mere inventiveness. In this context, Edison was very interested in patenting any invention he could. He had experienced enormous-for-the-times financial benefits from an invention while still in his twenties.

It was swept up in an enterprise that also emphasized the importance of legal protection.[418] Years of lawsuits swirled around these novel telegraph technologies, and Edison would take few legal chances with inventions thereafter.

He thus combined his pursuit of new products and techniques with a business development bent, and while the number 1,093 does not begin to describe the qualitative impact of Edison's life, patenting was one of his personal yardsticks for output.

A sampling of Edison Inventions *(Canada Science and Technology Museum).*

Edison's patents are, perhaps, more appropriately described in groupings as improvements and advances clustered around a few product lines such as electric light and power (389), phonograph (195), the telegraph (150), storage batteries (141), and telephones (34). In the same way, even though any quantitative estimates of Klein's output would cover a broad spectrum of inventiveness from small design features on a component part to integrated packages of interactive complexity, Klein's most enduring impact was the clustering of innovation and designs around major public concerns.[419]

The Klein numbers are absorbed into nuclear power safety systems around the world, imbedded in rehabilitation research procedures, intertwined with an array of northern aviation industry developments, and sprinkled over almost every improvement to housing, transportation, and the quality of lives surrounded by snow and ice.

Any estimate of the impact of Klein's work is, thus, a mathematical and intellectual product of many fields, many minds, and many souls.

And this was Klein's true, grand advantage.

The great American inventor stood at the apex of a pyramid as the inspiration and focus for creation in an inventive organization. Klein's pyramid was inverted. For most of his career, he stood under the spout of a funnel that held a swirling constellation of creative ideas and powerful influences.

Klein's work on the ZEEP reactor, for example, involved dozens of first-ever innovations. But Klein would have been a largely impotent presence at the site in Chalk River if he did not have the physicists, Kowarski and Watson-Munro, there to describe with precision what they needed. He would have had a much harder time without his technical colleague Don Nazzer and others who shared his enthusiasm.

Edison's electric light research was also stimulated by the inventor's contact with scientists, physicists studying a solar eclipse, and he too benefited from the support of great machinists, mechanics and rising scientists.

But Klein had such influences in the hundreds, and as scientific researcher with a mechanics bent and only an undergraduate degree, he retained a rare capacity to both respect the scientists and align with the machinists.

Edison struggled to appreciate the former all his life. He embodied a passing era and was ironically hobbled by the need to focus on his business.

Klein was a bridge between two eras and at the crossroads of innovation in country that not only passed through a period of dramatic national level events, but also an era of unprecedented growth and change in its scientific and technological character.

Klein's achievements were the result of his special talents finding a venue to link to the great issues and personalities of his time. For this reason, this book talks of people like wounded veteran John Counsell, whose founding of the Canadian Paraplegic Association and advocacy for the disabled led indirectly to Klein's opportunity to contribute uniquely to rehabilitation technologies. The heroic transfer of containers of heavy water out of occupied Europe by a multi-national, multi-cultural group to a remote, safe country named Canada also helps to explain the forces that made one man a great inventor. The opening up of Canada's north by adventuresome pilots, and the country's investments in medical research and health care also influenced Klein and gave him the capacity to create, invent, and serve.

These and other forces within modern Canadian history also prompted the creation of the National Research Council of Canada, the scene for Klein's great inventive productivity. While Klein and his colleagues were enthusiastically building NRC, Edison, approaching the end of his life, would not have been able to see the same potential in such a national organization of specialists.

> *"Edison never recognized how profoundly industrial research had changed by the end of his career as a growing body of technical and scientific knowledge made specialization a necessity. Perhaps if he had hired specialists to aid him in his later years Edison might have remained a significant figure in industrial research by meshing their talents and knowledge with his abilities as a generalist to define critical problems and judge among various solutions. But he failed even to build on his own experience and create a corporate research organization that could survive him and provide new inventions to assure the long-term health of his own company".*[420]

Klein on the other hand did build upon his own work by contributing to a lasting institution.

As the Nobel Year Book quote would suggest, NRC gained a reputation as "the only national research facility worldwide that was recognised as a genuine success" by the time Klein retired in 1969. NRC seemed to have it right as far as allowing people to create and invent in a productive way in those years.

Where it let people like Klein and his country down, perhaps, was in not turning more of those inventions into economic and industrial benefits. As the absence of patents and the give away of ideas suggest, it was not always a priority or seen as the best means of producing public benefits from research and development even though industries such as construction, aviation, space, and nuclear energy were clear beneficiaries of Klein's research and invention.

"If a Canadian had invented the light bulb, the world might have remained in the dark for another decade" would, nevertheless, be a joke to describe the challenges of technology transfer and business development in Canada and for NRC in the early days. Yet one might add that if Edison had worked at NRC, he could have invented it ten years sooner. Klein would have been spared the thousands of failed attempts that Edison surmounted in his electric light work because of the expertise and the resources around him at NRC. Certainly, the mysterious "Edison effect" recorded during the development of electric lighting would not have been missed as evidence of the electron by those who surrounded and supported Klein.

But these were different times and different places.

Today patenting at NRC is, indeed, regarded differently. It is a component of a complex portfolio of tools to engage industrial interests in both the development and exploitation of intellectual property. Collaborative agreements, licensing, and patenting can generate financial gain and money for research, but they are also seen as instruments to communicate, share benefits, and transfer technology to others.

NRC and the country its serves are making steps to address these issues as they enter the hyper-technological 21st Century. Creativity and inventiveness will be balanced by the drive to promote innovation and industry and other Canadian measures of impact and success. The pendulum will swing, and pulls in one direction will draw strength away from another. But early in the new century studies suggest that more correct decisions have been made than not.[421]

They also suggest that a country that could be identified at times as the most innovative may have produced the environment for a most productive inventor or, at the very least, a uniquely Canadian version of the great inventor.

APPENDIX 2. SOME INVENTIONS, DESIGNS, AND INNOVATIONS OF GEORGE J. KLEIN

Canada's First National Aeronautical Research Facilities

- Original apparatus and novel sub-components for research facilities including innovations such as the "Original design of vanes in the bends of the (NRC wind) tunnel" that also had "practical, industrial applications" in the design of "water, steam, and air ducts and passages". Also designed unique subsystems to give Canada's first national marine dynamics test basin the capacity to test model floats and hulls for aircraft as well as vessels and marine structures.

Aircraft Skis with Best Air and Ground Performance

- Numerous aircraft ski designs that improved stability and reduced air resistance including a streamlined ski for high performance aircraft, which "reduced drag by 80% and halved the pitching moment". Specialized equipment for the study of aircraft ski interaction with snow as well as ski designs "(that had a) … resistance (of)… less than half, and the tendency to "freeze in" … less than a third, of former values" and the successful ski design for the de Havilland *Beaver.*

Many WWII Military and Defence Projects

- Novel automatic sighting equipment for coastal defence artillery, many guns and firing equipment designs, improved versions of the "Wadkin type" of range and bearing radio receivers, mechanical gearing systems for anti-aircraft Radar, a photo flash bomb that could be set to go off at a prescribed height, the successful timing device for the proximity fuse, anti-submarine warfare equipment, *Weasel* all-terrain vehicle track design and components, an automatically inflated life jacket, and an acoustic mine sweeping technique.

Canada's First Nuclear Reactor, Engineering and Safety Equipment

- Complete engineering design on Canada's first nuclear reactor and the first to be built outside of U.S. (ZEEP); a model for other small research reactors, it required novel, materials, components, safety devices, monitoring equipment, control systems, and unique installation techniques that contributed to nuclear engineering.

The International System of Snow Classification

- A variety of novel devices and equipment for measuring the characteristics of snow as well as the basis of standards and methods for the first International System for the Classification of Snow.

First Wheelchair for Quadriplegics and Medical Engineering

- First practical electric-powered wheelchair for people with limited upper mobility along with innovations in terms of performance, cost, and reliability that helped establish performance testing standards and the rehabilitation engineering profession. Also a novel and effective blood vessel suturing device that allowed Canadian doctors to save lives and conduct early transplant surgeries.

Best Small-scale Windmill for Energy and Environmental Research

- Most efficient design of small-scale windmills for power generation for individuals as well as related test equipment. Also designed research equipment to assist studies of soil drifting by agriculture researchers and for research on anemometers to measure wind speed and direction in meteorological work. Also invented mounts and a configuration for three-camera aerial survey equipment that reduced the air resistance by 80% and improved aircraft stability for aerial survey work.

The Technology of Canada's Space Program

- Several contributions to a radio beacon that was a forerunner of the Crash Position Indicator including a STEM antenna, which was later developed for use in *Alouette I* and other satellite projects, all U.S. manned spacecraft in the Mercury, Gemini, and Apollo programs, and military and civilian applications. Provided design input as NRC's chief consultant on gearing systems for the Canadarm project.

Other Gadgets and Gears

- The "Induced Angle Calculator" instrument to apply Klein's aeronautical engineering techniques, a heavy dog sled for the RCMP, an automated model milling machine, an improved air compressor, industrial plant dust collection system, and many gear designs for other research and industrial equipment.

APPENDIX 3. TIMELINE

1835

- Alsatian brothers, John and George Klein (great grandfather of G.J. Klein) settle on Canada Company lands near Stratford, Ontario.

1842

- Another "George Klein" is born (near Sebringville, Ontario). Son of the settler and grandfather of inventor George J. Klein. Shortly after his birth, his mother dies. Elder George Klein remarries to Eliza Barr MacEwan two years later.

1852

- Alsatian settler, George Klein I, is killed in threshing machine accident.

1864

- His son, George Klein II, loses arm in threshing machine accident.

1867

- Confederation of British North American colonies. Ottawa is chosen as capital of new country.
- George Klein II marries Anna Steoppler Klein who gives birth to George (Stepler) Klein III (father of inventor).

1883

- Teenaged George Stepler Klein works at jeweller's in Stratford repairing watches.

1891

- Future NRC Director John Hamilton Parkin born in Toronto.

1899

- George Stepler Klein establishes jewellery, gold and silversmiths, and watch-making business in Hamilton. Marries Josephine Dinkel three years later.

1903

- Wright Brothers stage first controlled human flight at Kitty Hawk, North Carolina.

1904

- Josephine (Dinkel) Klein gives birth to future inventor George Johann Klein in Hamilton Ontario.

1908

- Casey Baldwin becomes first Canadian to fly an A.G. Bell plane at Lake Keuka, New York State. Next year J.A.D. McCurdy flies *Silver Dart* at Baddeck, N.S. in first flight in Canada. Seven-year-old George J. Klein meets McCurdy in 1911.

1914

- Britain declares war: Canada automatically involved.

1916

- Canadian Cabinet appoints Committee on Scientific and Industrial Research and later Honorary Advisory Council (HAC), forerunner of National Research Council of Canada (NRC).

1917

- University of Toronto mechanical engineer, J.H. Parkin, builds large-scale research wind tunnel to support war-time aviation industry

1918

- Armistice.
- HAC calls for national research institute and laboratories in Canada.

1920

- HAC appoints Associate Committee to promote and coordinate Aeronautical Research with Parkin as member.

1922

- Canadians led by Frederick Banting discover insulin later winning Canada's first Nobel Prize.
- A.G. Bell dies of diabetes.

1923

- H.M. Tory, future NRC President appointed chair of Honorary Advisory Council.

1924

- Research Council Act passed expanding scope of Council's mandate (name changed to National Research Council following year).
- G.J. Klein enters University of Toronto.

1928

- G.J. Klein graduates with Bachelor in Applied Science and takes Machine Design Demonstrator position at University of Toronto. Works in Parkin wind tunnel.
- Mackenize King Liberal government allocates NRC $750,000 to build national laboratories and establish research divisions including Physics and Engineering.

1929

- Parkin joins NRC in Ottawa as Assistant Director Physics Division.
- Klein hired as Junior Research Physicist (first NRC research employee).
- Construction begins on NRC National Laboratories at 100 Sussex.
- Gilbert Labine finds ore with uranium content at Great Bear Lake, NWT.
- Stock Market Crash and start of Great Depression.

1930

- Klein publishes first paper of Division of Physics on design of vanes and other innovations for the John Street wind tunnel.
- Mackenzie King Liberals fall from power with election of Bennett Conservatives.

1931

- NRC John Street Towing Tank finished. Wind tunnel finished later in the year.
- Thomas Alva Edison dies.

1932

- NRC Sussex Drive Laboratories opened.
- Rideau Canal and Klein family in Canada are both 100 years old.

1933

- Paper published on NRC wind tunnel design for first Streamlined Locomotive.

1935

- General A.G.L. McNaughton becomes NRC President.
- Mackenzie King Liberals return to power.

1936

- Klein expands work on aircraft skis from aerodynamics to interaction with snow.

1937

- Klein completes windmill design project.
- Klein and Binkley Jewellers fails.
- G.S. Klein (father of George J. Klein) dies, mother in hospital.

1939

- New York World's Fair unveils NRC designed Streamlined Locomotives: locomotives featured in pre-war Royal tour of Canada.
- Klein presents first results on snow research.
- In France, a team shows heavy water as best moderator for nuclear fission.
- War in Europe begins. Canada declares war separately as a sovereign country.
- NRC President McNaugthon transferred to armed forces.
- C.J. Mackenzie becomes Acting NRC President.

1940

- Heavy water physicists flee France with "world supply" of heavy water.
- Early nuclear research undertaken by George Laurence at NRC.
- Florence Elizabeth Schrie, born Pembroke, Ontario on January 20, 1916, marries George Johann Klein on October 4, 1940 at Zion Lutheran Church, Pembroke, Ontario.
    - George and Florence had one son, George Frederick Klein, born Ottawa, Ontario on August 5, 1942, who married Jeannette MacDonald, born in Halifax on February 17, 1946 and was living in Victoria, British Columbia in 2004. George has two sons.
        - George Michael Klein, born April 14, 1969.
        - Peter John Klein, born May 14, 1970, who married Juliette Sandwell on July 29, 1996.
    - George and Florence had one daughter, Margaret Joyce Klein, born Ottawa, Ontario on March 19, 1946, who married David Eric Thorsell on April 9, 1966. They have three children.
        - Karen Elizabeth Thorsell, born September 11, 1969 who married Hugh Wiggins on October 12, 1996.
            - Their children (great grandchildren of George J. Klein), are Lindsay Mary Frances Wiggins, born January 16, 1992, Ella Margaret Wiggins, born March 15, 1999, and Eric James Wiggins, born August 8, 2003;
        - Laura Anne Thorsell, born June 13, 1973,
        - Steven David Thorsell, born April 14, 1976, who married Cindy Evers on August 31, 2002.

1942

- Disastrous Dieppe Raid kills close to 1,000 Canadian soldiers. Lt. John Counsell paralysed and returns to Canada to found Canadian Paraplegic Association.
- Devil's Brigade formed as first such multinational force. Klein appointed to work on development of the Brigade's all terrain vehicle, the *Weasel*.

1944

- NRC established Turbo Research Ltd. in Toronto to develop jet engine. technologies in Canada. Klein helps design some research equipment.

1945

- Hiroshima and Nagasaki.
- Klein's ZEEP reactor goes critical at Chalk River, first nuclear reactor and first self sustaining chain reaction outside U.S.
- Soviet Embassy official Igor Gouzenko defects in Ottawa helping start Cold War.

1946

- Canadian Manufacturer's Association launches national touring exhibition of NRC inventions and helps establish industrial design profession in Canada.

1947

- First flights of de Havilland *Beaver*, first STOL (Short Take-off and Landing) plane. Klein later helps bush plane operators develop skis for all snow conditions.
- First Canadian conference on Snow issues. Klein reports on development of unique research equipment, snow classification, and national snow survey.
- NRX, large-scale nuclear reactor becomes operational at NRC Chalk River using ZEEP supported technologies. NRX is world's most powerful research reactor.

1948

- Klein presents plan for snow classification to International Conference in Oslo.

1951

- Snow classification system based on Klein design adopted as international standard by Commission on Snow and Ice.
- World's first Cobalt 60 cancer therapy systems introduced using isotopes produced at NRC Chalk River reactors.

1952

- Klein develops his STEM antennae invention for use in forerunner of Crash Position Indicator radio beacon project with Harry Stevinson.
- Atomic Energy Canada Limited (AECL) created as corporation to develop and commercialize Canadian technologies for peaceful application of nuclear science. C.J. Mackenzie leaves NRC to lead AECL. E.W.R. Steacie becomes NRC head.

1955

- Klein electric wheel chair for quadriplegics presented to U.S. Ambassador and U.S. Veterans Administration.

1957

- Sputnik launch highlights Soviet technological strengths.

1959

- Avro Arrow Project cancelled.

1960

- Klein's Blood Vessel suturing device patented.

1961

- Russian Yuri Gagarin is first man in space.
- J.F. Kennedy calls on U.S. to put man on the moon by 1970.

- G.J. Klein begins work as part-time Lecturer at Carleton University in Ottawa.

1962

- Canada becomes third country in space with *Alouette I* satellite carrying Klein's STEM antennae which becomes main product line for de Havilland Special Products and Applied Research (SPAR).
- NRC President E.W.R. Steacie dies.

1965

- NRC developed Crash Position Indicator credited with saving first lives.

1966

- NRC marks 50th anniversary.

1969

- *Apollo 11* lands on the Moon: one of many NASA manned space missions to use STEM antenna. SPAR sells STEM to other countries for many applications. George J. Klein retires from NRC after 40 years and becomes Adjunct Professor at Carleton University, receives honorary Doctorate from Waterloo Lutheran University (later Wilfrid Laurier University), appointed Officer of the Order of Canada.

1973

- NRC becomes lead agency in Canadarm project with George Klein as chief consultant on gear design; Spar aerospace as lead contractor.

1981

- Canadarm flies – Spar starts next generation Canadarm with Klein as consultant.

1988

- Klein receives honorary Doctorate from Carleton University.

1990

- Hubble Space Telescope, most sophisticated scientific research facility to leave the Earth, is launched. Its solar panels are extended using STEM technology.

1992

- George Johann Klein passes away at age of 88.

1993

- Klein posthumously inducted into Canadian Science & Engineering Hall of Fame.

1996

- NRC and Carleton University establish G.J. Klein medal to honour top high school students in national industrial design competition.

George J. Klein Medal Winners from the Design Exchange in Toronto which now runs the Canadian High School Design Competition started by Carleton University:

1997:
Peter Hunter & Martha Paynter, RCS Netherwood, Rothesay, NB
1998:
Valentin Florescu, Earl of March SS, Scarborough, ON
1999:
Nick Charney & Jason Chiasson; St. Peter Catholic H.S., Orleans, ON
2001:
Grace Poon, Sir Robert Borden H.S., Ottawa, ON
2002:
William Lo, Bayview SS, Toronto, ON
2003:
Jordan Palmer, Lockerby Composite School, Sudbury, ON
2004:
Ji Hye Park, Ridley College, St. Catherines, ON

ACKNOWLEDGEMENTS

George J. Klein died on November 4, 1992. I spoke to him briefly on the phone that year. I believe he was quite ill at the time, but I do not recall the specific conversation. This was the extent of my direct personal contact.

I am, therefore, deeply indebted to the many friends, colleagues, and admirers who supported me in this project. Dr. Lorne Gold, much-honoured Researcher Emeritus at the NRC Institute for Research in Construction (NRC-IRC), was more than helpful not only through interviews and access to rare documentation, but also through his comments on draft chapters pertaining to ice and snow research. As the former President of the International Glaciological Society and the scientist who established snow research at NRC on Klein's early work, Gold has a special knowledge of events and science, and his observations were treasured.

I was fortunate as well to talk and exchange material with Mr. Jack Templin, an aeronautical engineer and scientist who came to NRC in 1944 just in time to work in the still standing John Street wind tunnel designed by Klein fifteen years earlier. Templin was there to also participate in the formation of jet age research.

Dr. Jeremy Whitlock, Atomic Energy Canada Limited scientist at Chalk River destined to become President of the Canadian Nuclear Society, was kind enough to review and comment on the chapter about the ZEEP reactor as someone who has written on ZEEP and other features of early nuclear history. Dr. Garry Lindberg, first NRC Project Manager of the Canadarm, Director of the National Aeronautical Establishment, and, before retirement, Vice-President at the Canadian Space Agency, provided original information and comments on the Chapter entitled *Fingerprints on the Arm*. I am also indebted to experts such as Paul Penna and Jack's son Joe Templin of NRC's present day wind tunnels at the NRC Institute for Aerospace Research (NRC-IAR). The Canadian Bushplane Museum in Sault Sainte Marie put me in touch with Mr. Jack Minor, who prepared original and colourful material for my use on aircraft ski research in Ontario.

The prior writing of Professor Mary Tremblay at McMaster University on matters relevant to the chapter on Klein's electric wheelchair is, in fact, a more compelling story as she focuses even more intently upon the role and pull of the heroic Canadian patients. Her personal advice was also very helpful, particularly her guidance to special archival records, subsequently provided by the Department of Veterans Affairs Canada. Dr. Rory A. Cooper, Director of Rehabilitation Research at the University of Pittsburgh, who did not know George Klein, was supportive and generous with commentary and review of Klein's early technical reports pertaining to the ground-breaking wheelchair project. Dr. Randall Brooks, Curator at the Canada Science and Technology Museum, was, as usual, encouraging and helpful, particularly in tracking down the "original" Klein chair given to the U.S. government. It is now in storage at the Smithsonian Institution in Washington with the hope that it might visit Canada again someday.

I, of course, benefit from living in Ottawa close to the National Archives of Canada and the national museums. Dr. Cameron Pulsifer and the staff at the Hartland Molson Library at the Canadian War Museum touched me with their enthusiasm and assistance with regard to the *Weasel*, and I was delighted to have a chance to examine one in the Museum's Vimy House storage area.

Naturally, I am fortunate to have had access to the resources of the NRC Canada Institute for Scientific and Technical Information (NRC-CISTI), one of the world's great science libraries and storehouses of journals, technical papers, and documentation. NRC-CISTI, the arm of NRC that embraces this publisher NRC Research Press, also maintains and manages the NRC Archives. Mr. Gerald Neville, Manager of the NRC Research Press Monograph Publishing Program, Rob Forrest and Carol McKinley of his staff, and Dr. P.B. Cavers, Editor of the Monograph Program, honoured me with the invitation to write this biography. The successive archivists, Carole Julien, Lynn Delgaty, and Steven Leclair, were consistent sources of encouragement, research hand holding, and ideas

As indebted, I am to all of these people and many others, my greatest obligation is to thank George Klein's family: his charming widow Florence Klein, his kind children Margaret and George Jr., and their families. I thank them for their time, patience, and generous access to personal files, albums, and objects, but most of all for the privilege of writing about their loved one's life.

As per the dedication, my children Becky and Jonathon and others of their generation constitute the real object of this project and its purpose, and my parents and sister who taught me to enjoy a good story deserve my thanks. But my motivation is due to Michèle Bourgeois-Doyle, my life partner, friend, and first-round editor.

Any success this biography experiences will therefore be a function of a collective rather than the work of an individual, just like each of the many inventions of George Klein.

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6. Interviews and email exchanges with G.J. Klein's widow Florence Klein and daughter Margaret Thorsell in March and April 2003 are the sources of much of the Klein family history in this chapter.
7. Handwritten notes on family history written by George J. Klein in November 1982.
8. Canada's first Prime Minister John A. MacDonald was born in Scotland in 1815 came to Canada with his parents when he was 5 years old. Upper Canada rebel and reformer William Lyon Mackenzie was born March 12, 1795, at Dundee, Scotland. Engineer and inventor Sir Sandford Fleming was born in at Kirkcaldy, Scotland January 7, 1827.
9. George J. Klein family history notes and hand-drawn family tree November 1982.
10. Known later as "Granny McEwan" and someone whom "everybody loved". G.J. Klein notes 1982.
11. George Klein was married to Eliza Barr (MacEwan is the family name cited in Klein family records), both of the Township of Downie, on February 26, 1844 by the Rev. Daniel Allen. *In* F. Walker and R.W. Calder, *The Marriage Registers of Upper Canada/Canada West*. Volume 3, Huron District, 1841–1870. NorSim Research & Publishing, Delhi, Onatrio, 1995, p.7.
12. Tombstone marker, "Erected to the memory of George Kline (sic) who died Dec. 16 1852 A. 39 Yrs. A native of Alsace France". St. John's Ev. Lutheran Church Sebringville, Ontario as recorded by G.J. Klein.
13. Margaret Thorsell, daughter of George J. Klein, note April 2003.
14. *Ibid.*

15. George Klein (age 25 years) married Anna Stepler (age 20 years) on December 24, 1867. *In* E. Hancocks *County Marriage Registers of Ontario, Canada, 1858–1869.* Volume 17. Perth County. Generation Press, Agincourt, Onatrio.
16. Stepler was only one of several spellings of the family name. Changes in name spelling were a common experience for 19th century Upper Canada settlers, particularly, those who were not from Britain. Literacy was low, education was limited to whatever time could be spared from chores on the farm, and rural schools could not always quibble over the qualifications of teachers. George the Settler had his name misspelled on his tombstone, and George II was assigned the spelling "Cline" by his first teacher and lived with it for many years (source G.J. Klein hand-written notes).
17. George J. Klein's surviving sister, Marguerite, remembered the story as involving a jeweller and the first job being in Mitchell, Ontario. However, family records showed the boy George S. Klein working at W.H. Roberts Jeweller in Stratford, Ontario by the time he was 17 years old (pay was initially $3.00 per week rising to $5.00 and then $10.00)
18. "Clocks and Watches", p. 441–442. In *The Canadian Encyclopedia*, 2nd ed., Vol. 1. Hurtig Publishers, Edmonton, Alberta.
19. George S. Klein travelled to Columbus, Ohio in June 1891 at the age of 23 to work and study at the Columbus Watch Company, which had links to the famous Gruen watch company, and later was absorbed by the South Bend (Indiana) Watch company.
20. Weaver, John C., *Hamilton, an Illustrated History*. J. Lorimar and Museum of Nature, Museums of Canada, Toronto, Ontario, 1982. Front cover flap.
21. *Industrial Hamilton: A Trail to the Future* (History of Industry in Hamilton), Canada's Digital Collections, http://collections.ic.gc.ca/industrial/history.htm accessed March 21, 2003.
22. Binkley and G.S. Klein evidently worked together at another Hamilton jewellery and watch company before setting out in their own venture together as the early printed notices for their business state that "both (were) late of Davis and McCullough".
23. Interview with Margaret Thorsell, April 6, 2003.
24. In fact, George Johann Klein was the fifth (5th) George Klein in the family to live in Canada because the original settler brought his own parents, his father also being named George, over from the Alsace to join him and his family in Canada sometime before being killed in the farm accident at 39 in 1852.
25. Interview with Margaret Thorsell, April 6, 2003.
26. Etienne Brule in 1616 and the explorer LaSalle in 1669.
27. Weaver, *Hamilton, an Illustrated History*, pp. 96, 97, 175.
28. Catling, Christopher, *Florence and Tuscany: Eyewitness Travel Guides*, Dorling Kindersely Publishing Inc., London, 2002, pp. 66 and 106.
29. Comment made by G.J. Klein's sister Marguerite as relayed by G. J. Klein's daughter Margaret Thorsell in interview with author, March 2003.
30. Interview with Florence Klein, Ottawa, April 6, 2003.

31. George J. Klein was (1st) First in the class in these subjects at Hamilton Middle School Examination Report Cards for June 1922 and June 1923.

32. G.J. Klein resumé submitted to Carleton University 1961.

33. George J. Klein, Hamilton Technical High School Report Cards 1920–1924.

34. McMaster University, Canadian Encyclopedia online, http://www.thecanadianencyclopedia.com, accessed June 22, 2003

35. *Parkin Memoirs*, p. 140.

36. LLD Citation, University of Toronto, March 1961 as quoted in Foreword of Volume I, *Parkin Memoirs*, p. v

37. *Parkin Memoirs*, p. 210.

38. *Ibid.*, p. 219, 222.

39. *Ibid.*, p. 224.

40. *Ibid.*, p. 124

41. Forty years later Klein would resume teaching as a 60-plus, adjunct professor at Carleton University where students would recall him saying some of the same things that Parkin had said to students ("make things simple and easy for the machinists") 50 years earlier (comment by John Coleman, NRC manager, August 2003).

Chapter 2 — Helping Build Canadian Science

42. Les Prix Nobel Yearbook 1996, *Edited by* Tore Frängsmyr, Prof. of History of Science, Uppsala University, Sweden 1996 — Autobiographical article by Sir Harold Kroto, University of Sussex, Brighton, United Kingdom commenting on his first time at NRC in 1960s.

43. http://www.canadascapital.gc.ca/attractions/official_residences/rideauhall_e.html (2003)

44. Reference to Viscount Monck first Governor General, Shirley E. Woods, Jr., *Ottawa: The Capital of Canada* (1980: Doubleday Canada Limited (Toronto), Doubleday & Company, Inc. (Garden City, New York), p. 136.

45. Woods, Shirley, E., Jr., *Ottawa: The Capital of Canada* (1980: Doubleday Canada Limited (Toronto), Doubleday & Company, Inc. (Garden City, New York), p. 156.

46. *SPHERE*, NRC Newsletter (Dec 1990/Jan 1991 75th Anniversary Issue), Ottawa, p. 2.

47. *Ibid.*

48. Middleton, W.E.K., *Physics at the National Research Council of Canada, 1929–1952*, p. 21.

49. 100 Sussex Drive: The Temple of Science (Ottawa: National Research Council Canada Archives, 1989) p. 11.

50. Presentation Speech, Nobel Prize ceremony, awarding of 1971 Prize in Chemistry to Dr. Gerhard Herzberg, Sweden, http://www.nobel.se, accessed May 23, 2003.

51. Official Opening Program, National Research Laboratories, Ottawa, August 10, 1932, p. 13.

52. *Ibid.*, p. 13.
53. *Ibid.*, p. 14.
54. *Parkin Memoirs*, p. 209, 214, 215.
55. *Parkin Memoirs*, p. 341.
56. Middleton, W.E.K., *Physics at the National Research Council of Canada, 1929–1952*, p. 9.
57. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*. (Waterloo: Wilfrid Laurier University Press, 1984) p. 19.
58. Middleton, W.E.K., *Physics at the National Research Council of Canada, 1929–1952*, p. 10, 21.
59. *Parkin Memoirs*, p. 231.
60. Interview with retired NRC researcher Jack Templin May 2003.
61. *Parkin Memoirs*, p. 385.
62. Woods, Shirley E., Jr., *Ottawa: The Capital of Canada* (1980: Doubleday Canada Limited (Toronto), Doubleday & Company, Inc. (Garden City, New York), p. 260–261.
63. Interview at Klein home in Ottawa April 6, 2003.
64. Middleton, W.E.K., *Physics at the National Research Council of Canada, 1929–1952*, p. 22.
65. *Ibid.*, p. 22.
66. *SPHERE*, (NRC Newsletter (Dec 1990/Jan 1991 75th Anniversary Issue), Ottawa, p. 4
67. *Parkin Memoirs*, p. 347.
68. *Parkin Memoirs*, p. 350, 351 (Klein began design of the marine test basin in 1929 by himself and was later joined by K. Tupper in finishing the project).
69. The two buildings were on opposite sides of the original mill gate, *SPHERE*, NRC Newsletter (December 1990/January 1991 Issue), Ottawa, p. 3.
70. *Parkin Memoirs*, p. 347.
71. *Parkin Memoirs*, p. 355.
72. Famed University attended by NRC Nobel Laureate G. Herzberg and other notable physicists.
73. *Parkin Memoirs*, p. 358.
74. *Parkin Memoirs*, p. 357.
75. Middleton, W.E.K., *Physics at the National Research Council of Canada, 1929–1952*, p. 23.
76. Klein, G.J., Tupper, K.L., and Green, J.J., "Design of Corners in Fluid Channels", Can. J. Res. 3 (1930): 272–85.
77. *Parkin Memoirs*, p. 430.
78. *Parkin Memoirs*, p. 359.
79. "Wind Tunnel Testing" by Alan Pope, (1947) (reference provided by Jack Templin May 7, 2003).

80. The data on other wind tunnels of this period and observations here were provided in personal communications and interview with Jack Templin, retired NRC research manager, May 7, 2003.

81. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*. (Waterloo: Wilfrid Laurier University Press, 1984) p. 241.

82. Wind Tunnel Development of a Proposed External Form of a Steam Locomotive. J.J. Green. Can. J. Res. 8 (1933): 37–61. Middleton, W.E.K., *Physics at the National Research Council of Canada*, 1929–1952, p. 24.

83. *Ibid.*, p. 24.

84. *Parkin Memoirs*, p. 434.

Chapter 3 — The Science of Skis on Snow

85. Klein, George J., *Aeronautical Report AR-2: The Snow Characteristics of Aircraft Skis* (Ottawa: National Research Council of Canada, 1947), p. 3.

86. Wilson, Keith, *John Alexander Douglas McCurdy* (Canadian Biographical Series, Faculty of Education, University of Manitoba: Winnipeg, 1990), p. 17.

87. Careless, J.M.S. (Charles Humber, Publisher) *Visionaries: Canadian Triumphs* (Heirloom Publishing: Mississauga) http://collections.ic.gc.ca/heirloom_series/volume6?126–127.htm accessed January 29, 2003, p.2

88. Wilson, Keith, *John Alexander Douglas McCurdy*, p. 34.

89. Canada Aviation Museum (Curtiss JN-4 Canuck exhibit and Website, http://www.aviation.nmstc.ca./Eng/Collection/sd034e.htm January 28, 2003

90. Wilson, Andrew H. (*Editor*), *From Steam to Space: Contributions of Mechanical Engineering to Canadian Development* (Canadian Society of Mechanical Engineering: Ottawa, 1996) Chapter by G.F. Marsters, p. 191.

91. *Ibid.*, p. 191.

92. *Parkin Memoirs*, p. 224.

93. *Parkin Memoirs*, p. 226.

94. *Parkin Memoirs*, p. 227.

95. http://www.slktairport.com/airport_history.htm Accessed February 14, 2003.

96. Jack Minor, volunteer researcher, Canadian Bushplane Heritage Centre, Sault Sainte Marie, Ontario, Paper entitled "Elliot Brothers Aircraft Skis – Sioux Lookout, Ontario" February 28, 2003.

97. History of Bush Flying, Aviation and Forest Fire Management Historicial Information, Ontario Ministry of Natural Resources, Modified June 1, 2001 http://www.mnr.gov.on.ca/MNR/affmb/Aviation/History/bush_history.htm accessed 11/February/2003 p. 6.

98. Jack Minor, volunteer researcher, Canadian Bushplane Heritage Centre, Sault Sainte Marie, Ontario, Paper entitled "Elliot Brothers Aircraft Skis – Sioux Lookout, Ontario" February 28, 2003.

99. *Parkin Memoirs*, Appendix II, p. 8.

100. Wilson, Andrew H. (*Editor*), *From Steam to Space: Contributions of Mechanical Engineering to Canadian Development* (Canadian Society of Mechanical Engineering: Ottawa, 1996) Chapter by G.F. Marsters, p. 192.
101. Paul Penna, researcher, NRC Institute for Aerospace Research, interview with author, February 13, 2003.
102 Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 27 (spelled "Aidax" in this book).
103. Interview Paul Penna, researcher, NRC Institute for Aerospace Research, Ottawa with author February 13, 2003.
104. *Parkin Memoirs*, p. 436.
105. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 37.
106. Gliddon, C., Investigation into the Effect of weather Conditions on the Friction of Sleigh Runners on Snow. 1922 cited on p. 14 of George J. Klein, *Aeronautical Report AR-2: The Snow Characteristics of Aircraft Skis* (Ottawa: National Research Council of Canada, 1947).
107. *Parkin Memoirs*, p. 437.
108. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 38.
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110. Klein, George J., *Aeronautical Report AR-2*: The Snow Characteristics of Aircraft Skis (Ottawa:National Research Council of Canada, 1947), p. 3.
111. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 38.
112. *Ibid.*, p. 39.
113. *Ibid.*, p. 39.
114. *Ibid.*, p. 73.
115. The Snow Characteristics of Aircraft Skis – G.J. Klein, Report MM-57, February 1942 cited in *Parkin Memoirs*,p. 438.
116. Rossiter, Sean, *The Immortal Beaver: The World's Greatest Bush Plane* (Douglas & McIntyere: Vancouver/Toronto, 1996) Cover title.
117. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 239.
118. Rossiter, Sean, *The Immortal Beaver*, p. 30.
119. *Ibid.*, p. 33.
120. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 240.
121. Main, J.R.K., *Voyageurs of the Air* (Department of Transport Canada, Ottawa, 1967) p. 254.
122. *Ibid.*, p. 254.

123. G.J. Klein (Division of Mechanical Engineering), Aircraft Ski Research in Canada, Report No. MM-225 (Ottawa: National Research Council of Canada and Commonwealth Advisory Aeronautical Research Council).

124. Jack Templin, retired NRC researcher and wind tunnel manager, Ottawa, May 15, 2003 communication with author.

Chapter 4 – The Devil's Machine

125. Eggleston, Wilfrid, *Scientists at War* (London/Toronto/New York: Oxford University Press, 1950) p. 99 and War History reference therein.

126. Adleman, Robert H., and Walton, Col. George, *The Devil's Brigade* (Philadelphia – New York: Chilton Books , 1966) p. 178 (initially "the Black Devil's Brigade" drawing from a dead German officer's diary which talked of being surrounded by "the Black Devils" – FSSF men with faces blackened on night raids.)

127. *The Devil's Brigade (1968) starring Wm. Holden, Cliff Robertson, and Vince Edwards.*

128. *Peppard, Herb,* The LightHearted Soldier: A Canadian's Exploits with the Black Devils in WWII (Toronto: Nimbus Publishing Limited, 1994), p. vii, Introduction by William S. Story, Executive Director, FSSF Assn.

129. *Ibid.*, p. viii.

130. Lampe, David, *Pyke: the Unknown Genius* (London: Evans Brothers Limited, 1959) p. 156.

131. Citation Plaque at M-29C *Weasel*, Vimy House, Canadian War Museum Ottawa viewed March 2003.

132. Pyke was also the originator of a major project to build gigantic, powered icebergs to act as airbases in the North Atlantic. NRC was heavily involved in this questionable enterprise, and George Klein helped in a minor way with some of the liaison and coordination of the project known as Habbakuk in its early stages. See Lorne W. Gold, The Canadian Habbakuk Project, International Glaciological Society, Cambridge, 1993).

133. CBC Radio Interview, raw tape, National Archives of Canada, Ottawa (Interview primarily on ZEEP reactor): Interview by CBC Reporter of George Klein, September 5, 1975, National Archives of Canada A1 2002-10-0016, TRN ISN (1) (337756).

134. An ultimately tragic figure Pyke would take his own life at the age of 52 a few years after WWII.

135. Lampe, David, *Pyke*, p. 29.

136. *Ibid.*, p. 142–157.

137. *Ibid.*, p. 88–90.

138. *Ibid.*, p. 103.

139. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 141

140. Gregg, W.A. (*Editor*)., *Blueprint for Victory: The Story of Military Vehicle Design and production in Canada from 1937–54*, Canadian Military Vehicle Series, Vol. III, the Canadian Military Historical Society Inc. Rockwood, Ontario, p. 48.
141. *Ibid.*, p. 49.
142. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 38.
143. *Ibid.*, p. 39.
144. Burhans, Lieutenant Colonel Robert D., *The First Special Service Force: A War History of the North Americans 1942–1944* (Agincourt: Methuen Publications, 1981 –originally Washington: Infantry Journal Press, 1947) p. 12. "He (Pyke) insisted that the Canada Research Council work independently of OSRD to design a snow vehicle and asked that Canada's arctic experts be assigned to the task".
145. Some sources suggest that the codename was a suggestion from Churchill himself.
146. Interview by CBC Reporter of George Klein, September 5, 1975 National Archives of Canada A1 2002–10–0016, TRN ISN (1) (337756).
147. *Ibid.*
148. Eggleston, Wilfrid, *National Research in Canada: The NRC 1916–1966* (Toronto/Vancouver: Clarke, Irwin & Company Limited, 1978) p. 218.
149. Author interview with Florence Klein, Ottawa April 6, 2003.
150. Thistle, Mel (*Editor*)., *The Mackenzie-McNaughton Wartime Letters* (Toronto and Buffalo: University of Toronto Press, 1975) p. 120 (Letters from General McNaughton in 1942).
151. Later called Operation Jupiter.
152. Adleman, Robert H., and Walton, Col. George, *The Devil's Brigade*, p. 32.
153. *Ibid.*, p. 34.
154. http://www.vac-acc.gc.ca/general/sub.cfm?source = history/other/native/prince Department of Veterans Affairs website November 14, 2002 and book Devil's Brigade.
155. Peppard, Herb, *The LightHearted Soldier: A Canadian's Exploits with the Black Devils in WWII* (Toronto: Nimbus Publishing Limited, 1994), p. viii–ix, Introduction by William S. Story, Executive Director, FSSF Assn.
156. Adleman, Robert H., and Walton, Col. George, *The Devil's Brigade*, p. 36.
157. *Ibid.*, p. 33.
158. *Ibid.*, p. 35.
159. *Ibid.*, p. 35.
160. Critchlow, Donald T., *Studebaker: The Life and Death of an American Corporation* (Bloomington- Indianapolis: Indiana University Press, 1996) p. 118.
161. *Ibid.*, p. 120.
162. *Ibid.*, p. 119.
163. Department of Army Technical Manual, TM 9–2800, October 1947, p. 8.
164. Lampe, David, *Pyke*, p. 141–142.

165. Critchlow, Donald T., *Studebaker*, p. 119.
166. History of the Wartime Activities of the Division of Mechanical Engineering, National Research Council, Ottawa, Ontario, (no date), NRC Archives, p 154.
167. Eggleston, Wilfrid, *National Research in Canada*, p. 219.
168. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 141–143.
169. Eggleston, Wilfrid, *Scientists at War*, p. 99.
170. *Ibid.*, p. 99.
171. Eggleston, Wilfrid, *National Research in Canada*, p. 219.
172. *Ibid.* p. 220.
173. Eggleston, Wilfrid, *Scientists at War*, p. 99.
174. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 142.
175. Burhans, Lieutenant Colonel Robert D., T*he First Special Service Force: A War History of the North Americans 1942–1944* (Agincourt: Methuen Publications, 1981 –originally Washington: Infantry Journal Press, 1947) p. 38. "The *Weasel* ran away from its competition, and had to go back and tow in the tired skiers. It was a complete success. Here was Pyke's dream come true: a superior snow vehicle to give the Allies mastery of the snows".
176. Adleman and Walton, *The Devil's Brigade*, p. 87.
177. *Ibid.*, p. 88.
178. Critchlow, *Studebake*r, p. 120
179. Lampe, David, *Pyke: the Unknown Genius* (London: Evans Brothers Limited, 1959) p. 156.
180. Boniface, J.M., and Jeudy, J.G., Les véhicules de l'U.S. Army 1939–1945, Editions Presse Audivisuel 1987, p. 109.
181. Interview by CBC Reporter of George Klein, September 5, 1975, National Archives of Canada A1 2002–10–0016, TRN ISN (1) (337756).

Chapter 5 – Canada's First Nuclear Reactor

182. A communication to Nature, March 8, 1939 cited in Wilfrid Eggleston, *Canada's Nuclear Story* (Clarke, Irwin and Company, Toronto, Vancouver 1965) p. 30.
183. Eggleston, Wilfrid, *Canada's Nuclear Story*, Clarke, Irwin & Company Limited, Toronto/Vancouver, 1965, p. 21–22 describes the work. The term "explosion" relates to the above reference.
184. Lindsey, George R. (*Editor*), *No Day Long Enough: Canadian Science in World War II*, Canadian Institute of Strategic Studies, 1998, p. 238.
185. Labine, Gilbert, *Canadian Encyclopedia*, Hurtig, Edmonton, 1985, p. 956.
186. Bush Flying, *Canadian Encyclopedia*, p. 244.
187. Middleton, W.E.K., *Physics at the National Research Council of Canada, 1929–1952*, p. 10.

188. *Ibid.*, p. 10.

189. *Ibid.*, p. 22.

190. Laurence, George C., *Early Years of Nuclear Energy Research in Canada*, Publication of Atomic Energy Canada Limited, May 1980, p. 2. http://www.cns-snc.ca/history/early_years/earlyyears.html accessed September 23, 2002.

191. Hans Tammemagi, David Jackson, *Unlocking the Atom: The Canadian Book on Nuclear Technology*, McMaster University Press, 2002, p. 7.

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193. Laurence, George C., *Early Years of Nuclear Energy Research in Canada*, Publication of Atomic Energy Canada Limited, May 1980, p. 3 http://www.cns-snc.ca/history/early_years/earlyyears.html accessed September 23, 2002.

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196. Waltham, C. E., "A Brief History of Heavy Water", August 1998. http://www.physics.ubc.ca/~waltham/d2o98/paper/node7.html (Accessed August 22, 2003).

197. Eggleston, Wilfrid, *National Research in Canada*, p. 218.

198. *Ibid.*, p. 218.

199. The Mackenzie–McNaughton Wartime Letters, Ed. Mel Thistle, University of Toronto Press, 1975, p. 120

200. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 142.

201. Eggleston, Wilfrid, *Canada's Nuclear Story*, p. 49.

202. D.J. Phillipson taped Interviews with G.J. Klein, 1980 NRC Archives, Ottawa.

203. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 140.

204. National Research in Canada, the NRC 1916–1966, Wilfrid Eggleston, Clarke, Irwin and Company Limited, Toronto/Vancouver, 1978, p. 219.

205. Eggleston, Wilfrid, *Canada's Nuclear Story*, p. 83.

206. *Parkin Memoirs*, p. 632.

207. *Parkin Memoirs*, p. 632–633.

208. Laurence, George C., *Early Years of Nuclear Energy Research in Canada*, Publication of Atomic Energy Canada Limited, May 1980, p. 5.

209. Avery, Donald H., *The Science of War: Canadian Scientists and Allied Military Technology During the Second World War* (Toronto/Buffalo/London: University of Toronto Press Incorporated 1998) p. 202.

210. Eggleston, Wilfrid, *National Research in Canada*, p. 314.

211 Laurence, George C., *Early Years of Nuclear Energy Research in Canada*, Publication of Atomic Energy Canada Limited, May 1980, p. 6–7 (see web address above).

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215. Bothwell, Robert, *Nucleus: The History of Atomic Energy of Canada Limited*, p. 60.

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221. Eggleston, Wilfrid, *Canada's Nuclear Story*, p. 151.

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235. *Parkin Memoirs*, NRC, p. 631–633.
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Chapter 6 — The Seeds of Snow

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252. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 238.

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Chapter 7 — The First Wheelchairs for Quadriplegics

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302. Lowe, Ian R.G., Essay published in From Steam to Space: Contributions of Mechanical Engineering to Canadian Development p. 109, Canadian Society for Mechanical Engineering, 1996.

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304. *Parkin Memoirs*, Volume II, p. 707.

305. *Parkin Memoirs*, Volume II, p. 707. Parkin's remarks are consistent with, and likely drawn largely from Klein, G.J. A Wheelchair Electric Drive Designed for the use of Quadriplegics, National Research Council of Canada, Division of Mechanical Engineering, Report No. MM-234, 29 December 1953.

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312. Klein, G.J., Letter to Mr. E.A. Weir, Sunnybrook Hospital, Toronto, May 2, 1955.

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339. The War History of the Division of Mechanical Engineering, National Research Council, Ottawa (undated) p. 157.

340. Interview with Dr. Lorne Gold, Researcher Emeritus, NRC Institute for Research in Construction, Ottawa, April 15, 2003.

341. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 137.

342. *Ibid.*, p. 241.

343. Canadian Encyclopedia online, RCMP, author R.C. MacLeod. *The Canadian Encyclopedia* Copyright © 2003 Historica Foundation of Canada.

344. *Parkin Memoirs*, p. 634.

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352. Lindsey, George R. (*Editor*)., *No Day Long Enough: Canadian Science in World War II* (Toronto: Canadian Institute of Strategic Studies, 1997) p. 111.

353. Avery, Donald H., *The Science of War: Canadian Scientists and Allied Military Technology During the Second World War* (Toronto/Buffalo/London: University of Toronto Press Incorporated 1998) p. 103.

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356. Lindsey, George R., *No Day Long Enough*, p. 110.

357. Avery, Donald H., *The Science of War: Canadian Scientists and Allied Military Technology During the Second World War*, p. 105.

358. *Ibid.*, p. 69.

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360. *Parkin Memoirs*, p. 617–618.

361. In February 1941, (NRC) sold the U.S. War Department models of the Night Watchman and the GL Mark IIIC "at cost". Avery, Donald H., *The Science of War: Canadian Scientists and Allied Military Technology During the Second World War*, p. 81.

362. Middleton, W.E.K., *Mechanical Engineering at the National Research Council of Canada, 1929–1951*, p. 143.

363. *Parkin Memoirs*, p. 708.

364. Middleton, W.E.K., *Physics at the National Research Council of Canada, 1929–1952*, p. 24.

365. *SPHERE* May/June 1991 citing NRC Research News, Vol. 7, No. 8, August 1954.

366. Jack Templin, Letter to Margaret Thorsell, August 11, 1990 (Templin recalled the story as being the Governor General, but this is likely a confusion with the earlier paperweight event).

367. Tape No. 8, DJ Phillipson Oral History Interviews with George J. Klein, NRC Archives, Ottawa.

368. The War History of the Division of Mechanical Engineering, National Research Council, Ottawa (undated) p. 157.

Chapter 9 – Fingerprints on the Arm

369. Telephone interview with author July 1995.

370. Attributed without quotation marks to MacNaughton in Lydia Dotto, *A Heritage of Excellence: 25 Years at* Spar*Aerospace Ltd* .(Toronto: Spar Aerospace Ltd., and University of Toronto Press 1992) p. 38.

371. Notes on Taped Interviews with D.J.C. Phillipson, Tape #7 Feb. 1976, cite invention on S.S. *Franconia*, correlation with personal records provide dates, NRC Archives Ottawa.

372. Phone Interview with retired NRC researcher Jack Templin, Ottawa, April 2003.

373. Exhibit on George J. Klein, Canadian Science and Engineering Hall of Fame, Canada Science and Technology Museum, Ottawa, reviewed in April 2003.

374. *Parkin Memoirs*, p. 635.

375. *Parkin Memoirs*, p. 635.

376. *Parkin Memoirs*, p. 635.

377. A Spar manager also acted as a technical consultant on the Mission Impossible episode featuring a STEM antenna. Dotto, Lydia, *Heritage of Excellence*, p. 30.

378. Hasnain, Dr. Sadiq, *"The Crash Position Indicator Aviation Safety"*, National Research Council of Canada, Ottawa, April 1979 reprinted by IEEE Canada Millennium Achievements, p. 1–3. http://ewh.ieee.org/reg/7/showcase/millennium/cpi/cpi_about.html November 2003.

379. *Ibid.*

380. Jelly, Doris H., *Canada: 25 Years in Space* (Montreal: Polyscience Publications Inc. in cooperation with the National Museum of Science and Technology/National Museums of Canada, 1988) p. 23.

381. Hartz, Theodore R., and Paghis, Irvine, *Spacebound*,(Ottawa: Canadian Government Publishing Centre, Supply and Services Canada, 1982) p. 16.

382. *Ibid.*, p. 15.

383. Jelly, Doris H., *Canada: 25 Years in Space*, p. 107 cites this device. Others involved in *Alouette I* recall seeing the STEM first used on an army tank (*Spacebound*, p.57).

384. Dotto, Lydia, *A Heritage of Excellence: 25 Years of Spar*, p. 25.

385. Frank Mee, the head of the Spar Aerospace development laboratory, would, for example, patent many inventions incorporating STEM technology and apply it in many tasks. Lydia Dotto, *A Heritage of Excellence: 25 Years at* Spar *Aerospace Ltd* .(Toronto: Spar Aerospace Ltd., and University of Toronto Press 1992) p. 24.

386. Dotto, Lydia, *A Heritage of Excellence*, p. 23–25.

387. Jelly, Doris H., *Canada: 25 Years in Space*, p. 115.

388. Dotto, Lydia, *A Heritage of Excellence*, p. 25.

389. STEM: A Profile, Spar Aerospace products ltd. no date.

390. STEM was used for this purpose on the Appolo 17 lunar mission, its first use on Mercury missions were to improve high frequency transmissions prior to re-entry, but the antennas were not used during the re-entry stage, former Spar employee, H. Robert Warren, Ottawa in interview June 22, 2004.

391. Bingham, Richard, "To Infinity and Beyond", *Globe and Mail*, January 25, 2002, p. 54.

392. Spar's California based subsidiary was Astro Research Corporation, Spar also licensed the technology to other manufacturing interests such as NEECO Industries Ltd. of Burlington , Ontario and the Dutch Firm Zumro to develop lower cost products for other markets. Other products such as tripods using STEM legs and masts were sold in larger quantities and at lower prices than the space projects. Dotto, Lydia, *Heritage of Excellence*, p. 34.

393. Christopher Trump, a Spar Public Relations executive, was among those most responsible for promoting these stories during this period in books and articles.

394. Jelly, Doris H., *Canada: 25 Years in Space*, p. 129.

395. Garry Lindberg, telephone interview, Ottawa, May 2003.

396. Canadarm became widely accepted as the name for the robot arm and eventually added to official references and dictionaries.

397. Dotto, Lydia, *Heritage of Excellence*, p. 37.

398. This would be Canadarm 2 and the Special Purpose Dexterous Manipulator (SPDM) on the Space Station.

399. *SPHERE*, NRC Newsletter, "Farewell to Our Space Division", December 1989-January 1990, p. 6–7.

400. Bingham, Richard, "To Infinity and Beyond", *Globe and Mail*, January 25, 2002, p. 54.

401. Klein's STEM technologies were used in hundreds of space projects not only for Canada, U.S., and Europe, but also the Soviet program and Japanese spacecraft. It was even employed in the Hubble Space Telescope to extend solar panels. Dotto, Lydia, *Heritage of Excellence*, p. 23–48.

Chapter 10 — Brainstorming, Bicycles, And Birdhouses

402. Much of this chapter is based upon interviews with Florence Klein and her family in 2002 and 2003 and personal materials.

403. *Parkin Memoirs*, p. 692.

404. CBC Radio Interview, raw tape, National Archives of Canada, Ottawa (Interview primarily on ZEEP reactor): Interview by CBC Reporter of George Klein, September 5, 1975, National Archives of Canada A1 2002-10-0016, TRN ISN (1) (337756).

405. Harris, Kathleen, "A Very Special Neighbour", *New Edinburgh News*, Ottawa, December 1992.

406. *SPHERE*, NRC Newsletter, "George J. Klein: Close Up", Ottawa Fall 1988, p. 3 (Receives Honorary Degree from Carleton University).

407. George J. Klein entry in *The Canadian Encyclopedia* – author D.J.C. Phillipson.

408. Industrial Design. *The Canadian Encyclopedia* — Author Jacques Giard Copyright © 2003 Historica Foundation of Canada (May 27, 2003).

409. *Ibid.*

410. Doyle, Richard I., *Renaissance II: Canadian Creativity and Innovation in the New Millennium* (Report of the Millennium Conferences on Creativity in the Arts and Sciences), (Ottawa: NRC Research Press, 2001), p. 105–108.

411. *Ibid.*, p. 108.

Appendix 1. Edison and Klein

412. Israel, Paul, *Edison: A Life of Invention* (New York, Toronto, and other: John Wiley & Sons, Inc., 1998) p. vii.

413. *Ibid.*, p. 1.

414. Humber, Charles J. (Editor in Chief), Canadian Heirloom Series, Volume V, *Wayfarers: Canadian Achievers* (1996), (Mississauga: Heirloom Publishing Inc., 1996) p. 139 (Banting).

415. Jack Templin, retired NRC researcher, interview with author May 2003.

416. Wilson, Andrew H. (*Editor*)., *From Steam to Space: Contributions of Mechanical Engineering to Canadian Development* (Ottawa: Canadian Society for Mechanical Engineering, 1996) p. 134.

417. The *Parkin Memoirs* assign Klein approximately 10% of the space he devotes to the Division's technical history. The War History of the Division cites 3,317 project reports for this six (6) year period alone during which the NRC shops also addressed a total of 7,736 unique requisitions from Klein's Division.

418. "Edison, Thomas Alva". *Encyclopædia Britannica*. 2003. Encyclopædia Britannica Premium Service. 19 June 2003 – Edison sold his invention to industrialist Jay Gould, a competitor of his then supporter (Western Union) for $100,000 in stocks, bonds and cash.

419. "Edison, Thomas Alva". *Encyclopædia Britannica*. 2003. Encyclopædia Britannica Premium Service. 19 June 2003.

420. Israel, *Edison*, p. 472.

421. *The Economist Pocket World in Figures 2003 Edition* (The World Rankings, places Canada 1st in the Innovation Index on Business creativity and research, a measure of human resources skills, market incentive structures, and interaction between business and scientific sectors.) (London: The Economist in Association with Profile Books Ltd. 2002) p. 59.

SUBJECT INDEX

A

Alberta, University of 35, 40
Alouette I, Alouette II satellites 217-220, 251, 259
Alsace (Alsatian) 1-3, 5, 6, 21, 252
Antenna design 212, 219
Armaments, gun(s) 21, 89, 106, 190-193, 196, 200, 249
Atomic Energy Canada Limited (AECL) 123, 129, 135, 137, 138,203, 258

B

Beaver aircraft 91-94, 249, 257
Bellanca 79
Blood vessel suturing device 201, 203, 234 250, 258
Bush flying 47, 69, 72, 73, 77, 80, 93, 189

C

Cambridge (University) 32, 119, 120, 124, 126, 127, 129
Cams for artillery systems 200
Canadarm 211, 223-227, 251, 259, 261
Canada Company 2-4, 252
Canadian Institutes of Health Research (CIHR) 201
Canadian Manufacturers' Association 33, 239
Canadian National Railways (CNR) 62, 64, 66
Canadian Pacific Railways (CPR) 64–66
Canadian Paraplegic Association 165, 169, 247, 257
Canadian Science and Engineering Hall of Fame 238
Canada Science and Technology Museum 63, 202, 217, 238, 245, 262
Canadian Space Agency 226, 261
Cap Chat 204
Carleton University 35, 233, 234, 237, 240, 259, 260
Cavendish Laboratory 32, 119, 124
Chalk River 128, 131–138, 246, 257, 261
Cigarette box 206, 207
Cominco 125
Communications Research Centre (CRC) 218
CPI (Crash Position Indicator) 215, 216, 251, 258, 259
Crichton Street Elementary School 234

D

Defence, Department of National 44, 77, 82, 84, 218
Defence Research Board 158, 218
Defence Research Telecommunications Establishment (DRTE) 218, 219, 221
De Havilland 43, 79, 90–92, 219–221, 249, 257, 259
De Hacilland *Moth* series 78
Depression, the (Economic) 40–45, 47, 55, 59, 60, 62, 64, 77, 118, 122, 164, 165, 231, 254
Devil's Brigade, First Special Service Force (FSSF) 95, 96, 100–104, 106, 110–114, 123, 124, 257
Dieppe 97, 165, 257

E

Eldorado nuclear company 116, 117, 120
Everest and Jennings (E&J) 167, 169, 170, 175, 178–181

F

Ford (his car) 39, 224, 230
Fission 115, 118–124, 130, 134, 256

G

Gear (s), gearing 13, 16,23, 63, 78, 92, 150, 160, 173, 194, 197, 213, 223–225, 239, 249, 251, 259
Geodesy and Geophysics (International Union, IUGG) 145, 152, 153,157
Goodrich Rubber Company 108
Göttingen, University of 52
Göttingen wind tunnels 52, 53, 56
Grain-form Density Scale 154, 156

H

Hamilton, Ontario 11–18, 20–24, 27, 42, 45, 59, 60, 65, 70, 73, 113, 194, 229, 230, 239, 253
Hamilton Technical High School 21
Hawker *Audax* aircraft 79, 81
Heavy water 97, 123–130, 132–134, 136, 137, 247, 256
Hedgehog, anti-submarine system 198–200, 249
Hurricane (Hawker) aircraft 82, 89
Hydrology 143, 153, 158

I

Industrial Design 161, 238–240, 257, 260
Inuit 139, 140, 188–190, 193, 224
ISIS satellite 220

J

JEEP 137
Jet engine research 208, 209, 257
Jeweller(s), Klein and Binkley 12–15, 20, 22, 42, 59, 253, 255
John Street Labs 40, 46, 57, 60, 204, 244

K

Klein Chair 161, 173–182, 262
Klein Kit 149
Komatik (dog sled) 187–190, 193, 224, 251

M

Marine (towing wave tank, test basins) 47, 48, 50, 51, 117, 187, 206, 249
McGill University 35, 83, 119, 146
Mechanical Engineering (Division of) ix, 41, 60,91, 118, 130, 150, 169, 170, 185, 186, 213, 223, 239, 243, 244
Mission Impossible (TV show) 214
Montreal, University of 127
Musk Ox (military operation) 151

N

NASA, Mercury, Gemini, Apollo, Hubble 57, 211, 220, 223, 225, 226, 236, 251, 259, 260
National Aeronautical Establishment (NAE) 223, 231
NRC (National Research Council, Honorary Advisory Council) ix–xii, 24, 25, 30–42, 44, 47–49, 51–55, 59–65, 67, 73, 76–79, 81–83, 85, 86, 88, 90–93, 98, 101–103, 109, 110, 117–123, 125–130, 132, 136, 137, 143–151, 15, 158–162, 164, 166, 169–174, 176, 177, 179, 180, 185, 187, 189–193, 195–201, 203–209, 212, 214–219, 221–224, 226, 227, 230, 232–234, 236, 238, 239, 241, 243, 244, 247–249, 252–262
NRX (National Research Experimental) reactor 128, 130–137, 257
Norseman aircraft (*Noorduyn*) 77
Norway, Norwegian 97–99, 102, 106, 110–112, 123, 125, 137, 144, 152, 153
nuclear research 115, 120, 122, 124–126, 128, 130, 138, 196, 203, 256

O

Oil Crisis 203, 205
Ontario Provincial Air Service (OPAS) 73, 76, 90–94

P

pitchblende 116, 117, 187
Plough (Project) 99, 100, 102–106, 108, 113
Proximity Fuse 192–197, 249

R

Radar 60, 195–197, 217, 218, 249
radio beacon 212, 214, 215, 251, 258
Red Wing 70, 71
Rockcliffe (Airbase) 61, 81, 85, 89
RCAF 81, 83, 214, 219
RCMP (NWMP) Royal Canadian Mounted Police 188, 189, 251
Research Entreprises Limited (REL) 196, 197
Rideau Canal 51, 255

S

Saskatchewan, University of, 38
Scotland, Scot(s) 3, 5, 6, 124
Sebringville, Ontario 4, 8, 9, 252
Shops (NRC mechanical and instrumentation shops) xii, 27, 40, 47, 55, 85, 94, 134, 1554, 173, 185, 199, 200, 207, 243, 244
Silver Dart x, 18, 70, 71, 211, 224, 253
Sioux Lookout, Ontario 75, 86
Skis, aircraft 69, 70, 72–89, 91–94, 97, 100, 107, 117, 140, 144, 146, 186, 187, 189, 249, 255, 257, 261
Snow crystals 85, 142, 143, 154–157
Snow, International Commission, 88, 158
Snow recording penetrometer 87
Snow tools 143, 147, 149, 153, 158, 187
Spar Aerospace 211, 220–224, 226, 227, 232, 259
Space (program, Shuttle) 211, 223, 226, 227, 238
Sputnik 217, 218, 258
STEM antenna 211, 217, 219–223, 236, 243, 251, 258–260
Stratford, Ontario 4, 9, 10, 242, 252
Studebaker (Company) 8, 104–108, 110–113
Sussex (Drive Building) 32, 35–37, 40, 41, 44, 46, 47, 55, 57, 122, 224, 254, 255

T

Toronto, University of ix, 22–26, 34–36, 39, 42, 54, 55, 73,. 7, 76, 77, 82, 145, 204, 205, 233, 253, 254
Turbo Research Ltd. 208, 257

U

United States (U.S.) (projects with) 178–180
uranium 115–117, 119–122, 124, 127, 133, 134, 137, 254
Veterans Affairs (Department) 164, 165, 168–170, 175, 176, 179–181, 184, 243, 262

V

Vedette Aircraft (Vickers) 77
Violin, orchestras 45, 232, 233

W

Waterloo Lutheran University (later Wilfrid Laurier University) 237, 259
Watch, watch making, watchmaker 10, 11, 13–15, 17, 42, 192, 213, 232, 239, 242, 252, 253
Weasel, M-29 and M-29C 96, 99–114
Wheelchair (s) xii, 24, 161–163, 165–184, 201, 232, 234, 243, 250, 261, 262
Wind Tunnel (s) 22, 25–27, 34, 36–39, 51–57, 59, 61–67, 73–78, 80, 82, 83, 93, 94, 117, 204, 205, 244, 249, 253–255, 261
Windmill (s) 38, 39, 56, 204–206, 250, 255
World's Fair(s) 10, 62, 67, 239, 256
World War I, WWI 20, 21, 33, 60, 72, 73, 89, 95, 96, 163, 164
World War II, WWII 88, 90, 95, 96, 109, 112, 117, 118, 123, 126, 136, 142, 161, 163, 164, 166, 167, 183, 184, 191, 192, 195, 198, 208, 217, 249
Wright Brothers 17, 18, 53, 71, 253

Z

ZEEP nuclear reactor xii, 123, 129–138, 236, 246, 250, 257, 261

NAME INDEX

B

Baker, Doug xii
Baldwin, Frederick Walker "Casey" x, 17, 70, 71, 253
Banting, Sir Frederick 23, 201, 238, 254
Bell, Alexander Graham x, 17, 18, 70, 253, 254
Bell, C.A. 165, 168–170, 177, 180
Bentley, W.A. 142
Binkley, Thomas 13, 14
Bombardier, Armand 98, 106
Botterell, Harry 164, 165, 168, 175
Boyle, Robert William 37, 38, 46
Byrd, Admiral 76

C

Coates, W.H. 76
Cockcroft, Sir John 122, 127–130, 132, 136, 137
Counsell, John 165, 167–169, 176, 247, 257
Curtiss, Glenn 70

D

Dickins, Punch 117

E

Edison, Thomas A. 17, 241–248, 255
Elliot Brothers 75, 76, 84, 86
Everest, Herbert A. 166, 167

F

Fessenden, Reginald 20
Frederick, Robert T. 100–104, 106–108, 111, 114
Fleming, Alexander 162, 163
Fleming, Sir Sanford 3, 33
Freeth, Fred xii
Freeth, John xii

G

Garneau, Marc 226
Gold, Lorne 143, 160, 185, 261
Green, J.J. 41, 46, 53, 62, 63, 67, 79, 81
Gouzenko, Igor 138, 257

H

Halban, Hans von 115, 124, 125, 127, 129, 136
Henderson, J.T. 196
Herzberg, Gerhard 32, 238
Hiscocks, Richard (Dick) 91
Hopps, John 201
Howe, C.D. 127, 129, 136, 208, 239
Hughes, Col. Sam 72

J

Jennings, Harry 166, 167, 178
Joliot-Curie, F. 123, 124
Jousse, Al 165, 169, 175, 176

K

Kerwin, Larkin (NRC President) 226
King, William Lyon Mackenzie 30, 41, 254, 255
Klein, Anna [Stepler] 6–8, 252
Klein, Josephine [Dinkel] 11, 13, 14, 253
Klein, Florence [Schrie] (wife) 65, 66, 135, 229–232, 235, 256, 232
Klein, George I (great grandfather of George J. Klein) 2, 4, 6, 241, 252
Klein, George II (grandfather of George J. Klein) 4–9, 242, 252
Klein, George III (father of George J. Klein) 7–1, 13, 14, 20, 20, 59, 60, 242, 252, 253, 255
Klein, George (son of George J. Klein) 66, 232, 234, 235, 256, 262
Klein, Margaret [Thorsell] (daughter of George J. Klein) 66, 234, 235, 256, 262

Klein, Marguerite (sister of George J. Klein) 11, 13, 42, 233
Klein, Otto (brother of George J. Klein) 11, 13, 42
Klein, Robert (brother of George J. Klein) 11, 13, 17, 42, 43
Kowarski, Lew 123, 124, 128–130, 133, 135, 136, 137, 246
Kroto, Sir Harold 29
Kuhring, M.S. 41

L

Labine, Gilbert 116, 117, 120, 254
Laurence, George 118–123, 129, 256
Laurier, Wilfrid 13
Legget, Robert 145, 151, 158–160
Lindberg, Garry 223, 224, 226, 261
Lowe, Ian R.G. 243

M

MacDonald, John A. 29, 263
MacDonald, William 119
Mackenzie, C.J. 126, 127, 129, 130, 145, 190–192, 256, 258
Mackenzie, William Lyon 3, 29, 242, 255
Macleod, J.J.R. 23
MacNaughton, John D. (President of Spar) 211, 221
Mair, George xii
Marconi, Guglielmo 17, 18
Massey, Vincent 23
May, Alan Nunn 138
McCurdy, J.A.D. x, 18, 70, 71, 253
McEwan, Eliza 5, 6
McGill, Elizabeth (Elsie) 82, 83
McNaughton, A.G.L. (General and NRC President) 60, 126, 190, 192, 195, 196, 238, 255
Mountbatten, Lord Louis 97, 99, 100, 102, 103
Murphy, S.J. 199

N

Nazzer, D.B. (Don) xii, 131, 132, 136, 184, 246
Newton, Robert 40
Noorduyn, Bob 77

O

Oaks, Doc 73–76, 91
Owens, Robert xii, 171

P

Parkin, John Hamilton ix–xii, 24–27, 34, 36–41, 43–47, 50–52, 54, 56, 59–61, 73–76, 82, 118, 126, 130, 151, 158, 170, 184, 187, 190, 201, 205, 223, 236, 243, 252–254
Pearce, Don 160
Pearson, Lester B. 114
Phillipson, Donald J.C. xi, xii
Pitt, Arnold 193
Prince Philip, Duke of Edinburgh 206–208
Pyke, Geoffrey 96–100, 103, 105–107, 111, 124

R

Ross, Frank 55
Rutherford, Baron Earnest 119

S

Seligman142, 158, Gerald
Sicard, Arthur 146
Smialowski, A.J. (Tony) xii
Solandt, O.M. 158
Steacie, E.W.R. 32, 238, 258, 259
Stedman, E.W. 25
Stevinson, Harry 212, 214–216, 258
Stewart, Robert E. 179
Steel, W.A. 195

T

Templin, Jack 261

Thomson, Andrew 158
Tory, H.M. 35, 38, 40, 60, 254
Tunis (Lord Alexander of) 207
Tupper, K.F. 41, 46, 48, 50, 59
Turnbull, W.R. 25

W

Watson-Munro, Charles 130, 246
Whittle, Frank 208
Wilson, John Tuzo 146
Wright, Charles S. 141–143, 145

Z

Zinn, Walter 133